

Code of practice for

Maritime structures —

Part 1: General criteria

UDC 624.034.3/.4 + 69.034.3/.4

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Civil Engineering and Building Structures Standards Committee (CSB/-) to Technical Committee CSB/17 upon which the following bodies were represented:

- Association of Consulting Engineers
- British Ports Association and the National Association of Ports Employers
- British Steel Industry
- Concrete Society Limited
- Department of the Environment (PSA)
- Federation of Civil Engineering Contractors
- Health and Safety Executive
- Institution of Civil Engineers
- Institution of Structural Engineers
- National Ports Council
- Oil Companies International Marine Forum
- Scottish Development Department

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Coopted member

This British Standard, having been prepared under the direction of the Civil Engineering and Building Structures Standards Committee, was published under the authority of the Board of BSI and comes into effect on 30 April 1984

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The following BSI references relate to the work on this standard:
Committee reference CSB/17
Draft for comment 78/14623 DC, 78/14624 DC, 78/14625 DC, 79/10496 DC, 79/10539 DC and 79/11378 DC

ISBN 0 580 11966 1

Amendments issued since publication

Amd. No.	Date of issue	Comments
5488	December 1986	
5550	October 1987	
5942	September 1988	
6159	July 1989	
6393	June 1991	Indicated by a sideline in the margin

Contents

	Page
Committees responsible	Inside front cover
Foreword	x
Section 1. General	
1 Scope	1
2 References	1
3 Definitions	1
4 Symbols	2
Section 2. Environmental considerations	
5 General	6
6 Survey control	6
6.1 General	6
6.2 Level control	6
6.3 Location control	7
7 Meteorology and climatology	8
7.1 General	8
7.2 Wind	8
7.3 Precipitation	10
7.4 Air temperature and humidity	11
7.5 Visibility	11
7.6 Atmospheric pressure	12
7.7 Solar radiation and hours of sunshine	12
8 Bathymetry and topography	12
8.1 General	12
8.2 Echo sounder	13
8.3 Side-scan sonar	13
8.4 Direct measurement	14
8.5 Spacing and direction of sounding profiles	14
8.6 Wire sweep	14
8.7 Reduction of soundings	14
8.8 Coastal topography	15
9 Geotechnology	15
10 Water level	15
10.1 General	15
10.2 Tidal predictions	15
10.3 Meteorological effects	15
10.4 Tidal observations	16
10.5 Tidal analysis	16
11 Water movement	17
11.1 General	17
11.2 Measurement of advection	18
11.3 Measurement of diffusion	20
11.4 Presentation and analysis of field data	24
12 Waves	24
13 Water quality	24
13.1 General	24
13.2 Temperature	24
13.3 Chemistry	25
13.4 Turbidity	25
13.5 Marine life	25

	Page
13.6 Pollution	25
14 Sediment transport	26
14.1 General	26
14.2 Sediment transport in currents	26
14.3 Sediment transport with waves	28
14.4 Accretion and scour	29
14.5 Bed-form migration	29
14.6 Models	30
Section 3. Operational considerations	
15 General	30
16 Design life of structures	30
17 Ship data	31
17.1 General	31
17.2 Tonnage and displacement	31
17.3 Typical container ship and bulk carrier dimensions	31
18 Navigation in approach channels	31
18.1 General	31
18.2 Studies	32
18.3 Depth of channels	32
18.4 Width of channels	33
18.5 Other operational aspects	37
19 Ship handling	38
19.1 Manoeuvring inside harbours	38
19.2 Berthing	38
19.3 Mooring	39
Section 4. Sea state	
20 General	39
21 Wave characteristics	40
21.1 Wave forms	40
21.2 Basic wave properties	40
21.3 Sea state properties	41
21.4 Return period and design wave condition	41
22 Offshore wave climate	42
22.1 Wave generation	42
22.2 Wave prediction	43
22.3 Wave decay and swell	49
22.4 Extrapolation of offshore wave data	49
23 Shallow water effects	49
23.1 General	49
23.2 Refraction and shoaling	51
23.3 Bottom friction	53
23.4 Wave breaking	53
24 Long waves	62
24.1 General	62
24.2 Moving pressure fronts	63
24.3 Wave grouping effects	63
24.4 Tsunamis	63
24.5 Conclusions	63
25 Storm surge	64

	Page
26 Wave recording and analysis	64
26.1 Existing data sources	64
26.2 Site observations	64
26.3 Wave recorders	65
26.4 Analysis of records	66
27 Extrapolation of wave data	67
27.1 General	67
27.2 Extrapolation to extreme wave conditions	67
27.3 Extrapolation to individual maximum wave heights	68
27.4 Extrapolation of wave periods	69
28 Effects of breakwaters and sea-walls on sea states	71
28.1 General	71
28.2 Breakwaters in deep water	71
28.3 Breakwaters and sea-walls in shallow water	73
29 Harbour response	73
29.1 General	73
29.2 Wave diffraction for a flat seabed	74
29.3 Ray methods of wave diffraction and refraction	77
29.4 Harbour resonance	77
29.5 Physical models	79
29.6 Computational models	82
30 Acceptable wave conditions for moored boats	82
30.1 General	82
30.2 Marinas	83
30.3 Fishing harbours	83
30.4 Lighterage	83
31 Acceptable wave conditions for moored ships	83
31.1 General	83
31.2 Background information	83
31.3 Methods for determining acceptable sea states	84
31.4 Acceptable ship movements	87
Section 5. Loads, movements and vibrations	
32 General	88
32.1 Basic loads	88
32.2 Dynamic response	88
32.3 Spectral loading	89
32.4 Fatigue	89
33 Soil pressures	89
34 Winds	89
35 Snow and ice	89
36 Temperature variations	90
37 Tides and water level variations	90
38 Currents	90
38.1 General	90
38.2 Steady drag force	91
38.3 Flow-induced oscillations	91
39 Waves	93
39.1 General	93
39.2 Fatigue analysis	93

	Page
39.3 Design wave parameters	93
39.4 Wave forces	93
40 Earthquakes	96
41 Berthing	96
41.1 General	96
41.2 Operational factors	101
41.3 Fendering	102
41.4 Evaluation of berthing loads	102
41.5 Evaluation of berthing energy	102
42 Mooring	103
42.1 General	103
42.2 Evaluation of mooring loads	103
43 Docking and slipping	112
44 Cargo storage	112
45 Cargo handling and transport systems	112
45.1 General	112
45.2 Fixed and rail-mounted equipment	113
45.3 Conveyors and pipelines	113
45.4 Rail traffic	113
45.5 Road traffic	113
45.6 Rubber-tyred port vehicles	113
45.7 Tracked cranes	114
46 Channelized loading in pavements and decks	115
47 Movements and vibrations	117
47.1 General	117
47.2 Assessment of movements	117
47.3 Acceptability criteria	121
Section 6. Geotechnical considerations	
48 General	122
49 Site investigations	122
49.1 General	122
49.2 Existing data sources	122
49.3 Site reconnaissance	122
49.4 Exploratory drilling, sampling and in situ testing	123
49.5 Layout of boreholes and trial excavations	124
49.6 Depth of boreholes	124
49.7 Ground water investigations	124
49.8 Determination of earth pressure coefficient at rest	126
49.9 Detection of underground movements at depth	126
49.10 Geophysical surveys	126
49.11 Field trials	126
49.12 Studies related to constructional materials	127
50 Properties of the ground	127
50.1 Average properties for preliminary design	127
50.2 Selection of parameters for working design	128
51 Sheet piled structures	133
51.1 General	133
51.2 Types of sheet pile structure	133

	Page
51.3 Distribution of lateral earth pressure and earth resistance	134
51.4 Effects of surcharge	140
51.5 Hydrostatic pressure distribution	143
51.6 Stability of sheet pile structures	145
52 Gravity structures	150
52.1 General	150
52.2 Masonry and brickwork	151
52.3 Mass concrete walls	151
52.4 Concrete blockwork	151
52.5 Monoliths	153
52.6 Caissons	153
52.7 Design of gravity structures	153
53 Anchorage of structures	153
53.1 Function and location of anchorages	153
53.2 Methods of anchorage	153
54 Slope stability and protection	157
54.1 Environmental factors	157
54.2 Modes of failure	157
54.3 Design considerations for slopes and embankments	158
54.4 Monitoring stability	166
54.5 Slope protection	166
54.6 Maintenance of earthworks	167
54.7 Remedial works	167
55 Use of thixotropic liquids in excavations	168
55.1 Types of structure	168
55.2 Lateral earth pressure and earth resistance	168
55.3 Design of excavations for support by bentonite slurry	169
55.4 Materials	169
Section 7. Materials	
56 General	170
57 Stone for armouring or protection works	170
57.1 General	170
57.2 Tests of quality	170
57.3 Specification of size	170
58 Concrete	171
58.1 General	171
58.2 Chemical attack	172
58.3 Specification	172
58.4 Constituent materials	172
58.5 Hardened concrete	174
58.6 Fresh concrete	174
58.7 Curing	174
58.8 Reinforcement	174
58.9 Prestressing tendons, sheathing and grouting	174
58.10 Prevention of reinforcement corrosion	175
58.11 Underwater concrete	175
58.12 Other applications of concreting materials	176
59 Structural steel and other metals	176

	Page
59.1 General	176
59.2 Structural steel	177
59.3 Aluminium and its alloys	178
59.4 Other metals	178
60 Timber	179
60.1 General	179
60.2 Resistance to environmental hazards	179
60.3 Functional suitability	180
60.4 Fastenings	181
61 Piles	181
61.1 General	181
61.2 Bearing piles	181
61.3 Sheet piles	184
62 Pipes	185
62.1 General	185
62.2 Submarine pipelines	185
62.3 Underground pipelines	186
62.4 Surface pipelines	186
62.5 Flexible hoses	186
63 Pavements	186
63.1 General	186
63.2 Bitumen-bound flexible pavement	187
63.3 Tar-bound flexible pavement	187
63.4 Concrete block pavement	188
63.5 Precast concrete slab pavement	188
63.6 In situ concrete pavement	188
64 Rail track	188
64.1 General	188
64.2 Bedding system	189
64.3 Holding-down bolts	189
64.4 Rail clips	189
64.5 Heavy duty crane rails	189
64.6 Bolted joints	189
65 Brickwork, blockwork and masonry	189
66 Bituminous materials	190
66.1 General	190
66.2 Bituminous materials available	190
66.3 Composition, mix design and application techniques	190
66.4 Uses of bituminous materials	192
67 Rubber and plastics	193
67.1 General	193
67.2 Natural and synthetic rubbers	193
67.3 Plastics	194
68 Protective measures	194
68.1 General	194
68.2 Coating systems	195
68.3 Concrete protection	195
68.4 Monel 400 sheathing	195

	Page
68.5 Steel wear plates	195
68.6 Wrappings	195
68.7 Cathodic protection	196
68.8 Protection in the buried zone	196
Appendix A Physical properties of commonly stored cargoes	197
Appendix B Method of test for soundness of aggregate by use of sodium sulphate or magnesium sulphate	197
Appendix C Bibliography	201
Figure 1 — Typical ship dimensions	34
Figure 2 — Estimates of squat	36
Figure 3 — Vertical ship movements due to waves in deep water	37
Figure 4 — <i>Figure deleted</i>	44
Figure 5 — <i>Figure deleted</i>	44
Figure 6 — Significant wave prediction chart	45
Figure 7 — JONSWAP wave spectrum	47
Figure 8 — Pierson-Moskowitz spectrum	48
Figure 9 — Significant wave height and peak period for wave spectra	50
Figure 10 — Schematic diagram of wave refraction	54
Figure 11 — Wave shoaling and estimation of wave height in the surf zone	55
Figure 12 — Wave height reduction factor for bottom friction	61
Figure 13 — Typical wave height extrapolation plot	70
Figure 14 — Variation of $(H_{\max}/H_s)^2$ with N	72
Figure 15 — Run-up on graded riprap slope	75
Figure 16 — Run-up on rubble-mound slope	75
Figure 17 — Wave diffraction at single breakwater arm	76
Figure 18 — Wave diffraction intensity factors for narrow breakwater openings	80
Figure 19 — Wave diffraction at narrow breakwater opening	81
Figure 20 — The six degrees of freedom of vessel movement	86
Figure 21 — Critical flow velocity for circular piles for in-line oscillations	92
Figure 22 — Wave pressure distribution at reflective walls for non-breaking waves	97
Figure 23 — Estimation of alpha values for calculation of wave pressure	98
Figure 24 — Drag coefficient values for circular cylinders	100
Figure 25 — Current force coefficients, all ships, deep water case	105
Figure 26 — Envelope of wind force coefficients for dry cargo vessels and small tankers	106
Figure 27 — Wind force coefficients for very large tankers with superstructures aft	107
Figure 28 — Wind force coefficients for typical container ship	108
Figure 29 — Water depth correction factors for lateral current forces	109
Figure 30 — Water depth correction factor for longitudinal current forces on container ships	109
Figure 31 — Envelope of longitudinal force coefficients for VLCC's in shallow water	110
Figure 32 — Typical lengths and draughts of tankers	110
Figure 33 — Typical longitudinal projected areas of tankers	111
Figure 34 — Container ships: lengths and longitudinal projected areas	111
Figure 35 — <i>Figure deleted</i>	112

	Page
Figure 36 — <i>Figure deleted</i>	112
Figure 37 — <i>Figure deleted</i>	112
Figure 38 — Dimensions of RT vehicle	116
Figure 39 — Thickness and mass of marine growth in British coastal waters	119
Figure 40 — Location and depth of boreholes for piled wharf	125
Figure 41 — Depth of boreholes in relation to retained height of soil and width of quay wall	125
Figure 42 — Plane strain shear diagram for sand	132
Figure 43 — Plane strain shear diagram for normally-consolidated clay	132
Figure 44 — Anchored single-wall sheet pile structure	135
Figure 45 — Cantilevered single-wall sheet pile structure	135
Figure 46 — Double-wall sheet pile structures	136
Figure 47 — Cellular sheet pile structures	137
Figure 48 — Anchored cellular sheet pile structure	138
Figure 49 — Distribution of earth pressure and earth resistance on cantilevered single-wall sheet pile structure	141
Figure 50 — Distribution of earth pressure and earth resistance on anchored single-wall sheet pile structure	142
Figure 51 — Active pressure distribution on anchored single-wall structure where filling is placed before dredging	142
Figure 52 — Active pressure distribution on anchored single-wall structure where filling is placed after dredging	143
Figure 53 — Distribution of active pressure and passive resistance for total stress conditions in normally and lightly over-consolidated clay	143
Figure 54 — Hydrostatic pressure distribution on waterfront structures where soil is retained to full height of structure	146
Figure 55 — Hydrostatic pressure distribution on waterfront structure where soil is embanked behind the structure	146
Figure 56 — Hydrostatic pressure behind waterfront structure backed by clay	147
Figure 57 — Effects on hydrostatic and soil pressure distribution where seepage takes place beneath retaining structure	147
Figure 58 — Effects of flexibility of anchored single-wall sheet pile structure on earth pressure and resistance	148
Figure 59 — Location of anchorages in relation to rupture surfaces in retained fill	149
Figure 60 — Simplified distribution of active earth pressure and passive earth resistance on cantilevered single-wall sheet pile structure	149
Figure 61 — Distribution of active earth pressure and passive earth resistance on double-wall sheet pile structure	150
Figure 62 — Distribution of active earth pressure and passive earth resistance on cellular sheet pile structure	151
Figure 63 — Modes of failure of cellular sheet pile structure	152
Figure 64 — Anchorage of lock or dry dock against hydrostatic uplift	156
Figure 65 — Raking piles used to restrain horizontal movement of jetty	156
Figure 66 — Location of wall or plate anchors in relation to failure surfaces	159
Figure 67 — Location of injected tendon anchors in relation to active failure wedge	159
Figure 68 — Failure of vertical anchor tendon due to uplift of cone of soil or rock	160

	Page
Figure 69 — Modes of failure of anchor tendons in rock	160
Figure 70 — Anchorage of single-wall sheet pile structure by raking piles	161
Figure 71 — Types of slope failure	162
Figure 72 — Failure of embankment due to shear failure of supporting soil	163
Figure 73 — Compound slide	163
Figure 74 — Slab slide in rock	163
Figure 75 — Wedge failure in rock	164
Figure 76 — Toppling failure in rock	164
Figure 77 — Embankment built in stages with core material protected by dumped stone	167
Figure 78 — Slope protection by rock or concrete armouring backed by filter layer	168
Table 1 — Diffraction coefficients for single breakwater arm	78
Table 2 — Typical frequencies of environmental forces	88
Table 3 — Effective temperature range for maritime structure decks in British coastal waters	90
Table 4 — Modification factors for critical flow velocity	92
Table 5 — Drag and inertia coefficients for common structural forms	101
Table 6 — Suggested transverse berthing velocities	102
Table 7 — Nominal bollard and fairlead loadings for vessels up to 20 000 t displacement	103
Table 8 — Typical stacking heights	112
Table 9 — Equivalent uniformly distributed loading for rubber-tyred port vehicles	114
Table 10 — FLT loading: dimensions, loads and effective contact pressures	115
Table 11 — Side-loader jack reactions	115
Table 12 — Mobile crane outrigger reactions	115
Table 13 — RT loading: axle loads and effective wheel pressures	115
Table 14 — Loading due to tracked cranes	116
Table 15 — Typical throughputs for new cargo handling berths	116
Table 16 — Added mass of entrained water	120
Table 17 — Mobilized angle of friction	128
Table 18 — Physical characteristics of soils and rocks	131
Table 19 — Values of K_A , the coefficient for active earth pressure	141
Table 20 — Values of K_p , the coefficient for passive earth resistance	141
Table 20A — Cements	173
Table 21 — Minimum cement content	174
Table 22 — Typical upper rates of corrosion for structural steels in UK maritime conditions	177
Table 23 — Uses of bituminous materials in maritime protection works	193
Table 24 — Typical dry bulk densities and angles of repose	197
Table 25 — Typical stacked densities for common commodities	197
Table 26 — Sieve sizes for fine aggregate fractions	199
Table 27 — Sample mass for coarse aggregate fractions	199
Table 28 — Sieve size to determine loss	200
Publications referred to	205

Foreword

This standard has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee.

Following suggestions from the Maritime and Waterways Board of the Institution of Civil Engineers, the Standards Committee for Civil Engineering Codes of Practice set up an ad hoc panel to make further studies. The panel's report, presented in 1975, concluded that existing British codes were inadequate for the special aspects of maritime structures and that there was a need for such a code. A format was proposed which divided the work into two distinct stages.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been prepared.

In this Part of the code, recommendations are given to assist clients and engineers to obtain the basic data relevant to the design of any maritime structure. It has been assumed that limit state philosophy will wherever possible be adopted for the design. However, it should be noted that certain phenomena, such as resonance and fatigue, cannot be treated rigorously by this method and a satisfactory adaptation of limit state methods has yet to be established as a practical basis for the geotechnical aspects of the design. Partial factors are not included in this Part, it being intended that these be given in subsequent Parts covering the limit state design of specific maritime structures.

It is planned to complete the code with a further seven Parts which would deal with the following:

- a) the design of quay walls, jetties and dolphins;
- b) the design of locks and graving docks, slipways and ship lifts;
- c) the design of lock and dock gates, caissons and sluices;
- d) the design of buoy moorings, floating and buoyant structures and anchorage systems;
- e) the design of breakwaters and training walls;
- f) the design of fendering and mooring systems;
- g) recommendations for the dredging of water-ways and for land reclamation.

NOTE The numbers in square brackets used throughout this code relate to the bibliographic references in Appendix C.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to x, pages 1 to 206, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This Part of BS 6349 gives guidance and recommendations on general criteria relevant to the planning, design, construction and maintenance of structures set in the maritime environment. By definition, the structures to which this code is applicable will be located at, or close to, the shore. Offshore structures and structures in inland waters are not covered by this code although certain aspects may be found to be relevant to such projects.

Guidance is not given on financial criteria although it should be recognized that for each project necessary and proper economic assessments should be made and considered in conjunction with the engineering criteria covered by this code.

This code has been written in relation to conditions which obtain in the UK and while the majority of the contents are directly applicable elsewhere, local conditions or sources may necessitate appropriate modifications.

This Part of the code is arranged on a topical basis. Section 2 discusses environmental factors, in which the environment is taken in its broader sense to include all naturally occurring phenomena likely to be found at a coastal site and guidance is given on methods of investigating and quantifying their effects. Section 3 gives prominence to the need to consider operational requirements throughout the planning of maritime works although only limited guidance is given on some general aspects since the detailed functional requirements of individual structures are beyond the scope of this Part of this code. Section 4 discusses sea state and gives guidance on the characteristics, prediction, recording and effect of waves. Section 5 deals with the selection and evaluation of design loadings arising from the environmental and operational effects discussed in the previous sections, taking due account of dynamic response and fatigue. Section 6 discusses geotechnical aspects, including ground investigations, soil parameters, and geotechnical design requirements. Section 7 gives guidance on the use and specification of appropriate materials and protective measures.

2 References

The titles of the publications referred to in this standard are listed on page 205.

3 Definitions

For the purposes of this Part of BS 6349 the following definitions apply.

NOTE For other terms not separately defined the meanings follow the general usage of the maritime engineering industry.

3.1 Tides

3.1.1 semi-diurnal tides

tides that have two high waters and two low waters in a lunar day of approximately 25 h

3.1.2 diurnal tides

tides that have one high water and one low water in a lunar day

3.1.3 range

the difference in height between one high water and the preceding or following low water

3.1.4 spring tides

the two occasions in a lunar month when the average range of two successive tides is greatest

3.1.5 neap tides

the two occasions in a lunar month when the average range of two successive tides is least

3.1.6 mean high water springs (MHWS)

the average, over a long period of time, of the heights of two successive high waters at springs

3.1.7 mean low water springs (MLWS)

the average, over a long period of time, of the heights of two successive low waters at springs

3.1.8 mean high water neaps (MHWN)

the average, over a long period of time, of the heights of two successive high waters at neaps

3.1.9 mean low water neaps (MLWN)

the average, over a long period of time, of the heights of two successive low waters at neaps

3.1.10 mean sea level (MSL)

the average level of the sea surface over a long period, preferably 18.6 years (one cycle of the moon's nodes), or the average level which would exist in the absence of tides

3.1.11**lowest astronomical tide (LAT)**

the lowest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

NOTE It is often the level selected as the datum for soundings on navigational charts.

3.1.12**highest astronomical tide (HAT)**

the highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

3.2 Ship tonnages**3.2.1****gross registered tonnage (grt)**

the gross internal volumetric capacity of the vessel as defined by the rules of the registering authority and measured in units of 2.83 m^3 (100 ft^3)

3.2.2**deadweight tonnage (dwt)**

the total mass of cargo, stores, fuels, crew and reserves with which a vessel is laden when submerged to the summer loading line

NOTE Although this represents the load-carrying capacity of the vessel it is not an exact measure of the cargo load.

3.2.3**displacement**

the total mass of the vessel and its contents

NOTE This is equal to the volume of water displaced by the vessel multiplied by the density of the water.

3.3 Waves**3.3.1****wave height**

the height of a wave crest above the preceding wave trough

3.3.2**wave period**

the time for two successive wave crests to pass a fixed point

3.3.3**wavelength**

the distance between consecutive wave crests

3.3.4**phase velocity**

the speed at which a wave propagates

NOTE The terms “wave celerity” and “velocity of wave propagation” may also be used to describe phase velocity.

3.3.5**wave steepness**

the wave height divided by the wavelength

3.3.6**group velocity**

the velocity of propagation of a train of waves, i.e. the velocity at which the energy of the wave train travels

3.3.7**significant wave height**

the average height of the highest one third of the waves

3.3.8**significant wave period**

the average of the periods of the highest one third of the waves

3.3.9**zero-crossing wave period**

the average period of all the waves with troughs below and crests above the mean water level

3.3.10**spectral density**

a measure of the energy of the sea state expressed as a function of wave frequency and direction

4 Symbols

The following symbols are used in this Part of this code. Several meanings are given to some of the symbols and the specific meaning is given in each case in the text where the symbols are used.

A	Cross-sectional area.
A_L	Longitudinal projected area of vessel above waterline.
A_n	Area normal to flow.
a	Exponent in JONSWAP spectral density function.
B_v	Beam of vessel.
B_e	Breadth of earth-retaining structure.
b	Wave ray separation.
b_a	Wave ray separation at arrival point.
b_0	Wave ray separation in deep water.
C_B	Block coefficient.
C_{CL}	Depth correction factor for longitudinal current forces.
C_{CT}	Depth correction factor for transverse current forces.
C_c	Shallow water correction factor.
C_D	Drag force coefficient.
C_I	Inertia force coefficient.

C_{LC}	Longitudinal current force coefficient.	F_{TW}	Transverse wind force.
C_{LW}	Longitudinal wind force coefficient.	F_V	Vertical soil friction force.
C_M	Hydrodynamic mass coefficient.	F_W	Total wave force.
C_S	Slamming force coefficient.	F_1	Soil force (similarly F_2 and F_3).
C_{TC}	Transverse current force coefficient.	F_B	Bed friction stress.
C_{TW}	Transverse wind force coefficient.	f	Wave frequency.
c_u	Undrained shear strength of soil.	f_c	Frequency of cyclic loading.
c'	Effective cohesion.	f_m	Frequency at which peak occurs in spectrum.
D_{50}	Median size of graded stone (other subscripts for different percentages passing).	f_N	Natural frequency of structure or member.
d	Still water depth.	g	Acceleration due to gravity.
d_p	Sheet pile penetration.	H	Wave height.
d_e	Effective depth of sheet pile penetration.	H_R	Retained height of structure.
d_c	Maximum displacement under cyclic loading.	H_a	Wave height at arrival point.
d_0	Deep water depth.	H_b	Breaking wave height at structure.
d_1	Water depth at one wavelength from wall.	H_{inc}	Incident wave height.
d_t	Depth of tension crack.	H_n	The n th height or height interval in a rank-ordered set of n_x values.
d_x	Effective embedment of sheet piles.	H_{max}	Maximum wave height.
d_A	Depth of lowest trough below wave chart mean line.	$\bar{H}_{max}$	Average maximum wave height.
d_B	Depth of second lowest trough below wave chart mean line.	H_{n_x}	The n_x th (maximum) height or height interval in a rank-ordered set of n_x values.
d_m	Mean draught of vessel.	H_0	Wave height in deep water.
d'	Depth below still water level of bottom of wall.	$H_{r\theta}$	Wave height at position (r, θ) .
d_b	Depth of water $5 \times H_s$ from wall (H_s calculated for depth " d ").	H_s	Significant wave height.
d_m	Depth of water over mound.	$H_{s,n}$	The n th significant wave height in a set.
E	Effective kinetic energy of berthing vessel.	$H_{s,1}$	Component significant wave height from wave chart (similarly $H_{s,2}$).
e	The exponent function.	H_1	Component wave height from wave chart (similarly H_2).
F_D	Drag force.	H_r	Height of retained soil.
F_H	Horizontal soil friction force.	H_{0c}	Clapotis set-up.
F_I	Inertia force.	H_{sd}	Significant height of set-down.
F_{LC}	Longitudinal current force.	H_A	Height of highest crest above wave chart mean line.
F_{LW}	Longitudinal wind force.	H_B	Height of second highest crest above wave chart mean line.
Fr	Froude number.	H_L	Limiting wave height in probability distributions.
F_S	Wave slam force.		
F_{TC}	Transverse current force.		

H_w	Height of wave run-up above still water level.	l'	Length of cylinder from water level to apparent fixity.
H_z	Height of wind measurement above sea surface.	m_D	Displacement of vessel.
H_D	Design wave height.	m_{50}	Median mass of graded stone.
$H_{1/250}$	Mean height of the 0.4 % highest waves.	m_L	Mass per unit length of member.
H_0'	Effective deep water wave height.	$\overline{m}$	Equivalent excited effective mass per unit length of member.
h_c	Height of top of wall above still water level.	m_e	Equivalent mass of structure.
$I(f, \phi)$	Spectral density function.	m_c	Machine payload capacity.
$I_0(f, \phi)$	Offshore spectral density function.	m_s	Mass of cellular structure and contained soil.
$I_D(\theta)$	Wave diffraction intensity factor.	N	Number of waves in design condition duration.
i	Number designating a stress range.	N_s	Scale factor.
J	Ratio of offshore wave steepness to square of beach slope.	N_i	Number of waves in i th stress range during design life.
K_A	Coefficient of active earth pressure.	N_z	Number of zero up-crossings on wave record.
K_d	Wave diffraction coefficient.	n	A number between 1 and n_x .
K_f	Wave height reduction factor due to bed friction.	n_T	Total number of stress ranges.
K_0	Coefficient of at-rest earth pressure.	n_x	A number.
K_p	Coefficient of passive earth resistance.	n_i	Number of waves in the i th stress range during design life.
K_r	Wave refraction coefficient.	P	Maximum applied cyclic load.
K_s	Wave shoaling coefficient.	P_A	Active soil force per unit length of wall.
K_1	Empirical added mass coefficient (similarly K_2 and K_3).	$P_{\max}$	Maximum water pressure on wall at seabed.
K_b	Bed friction factor.	$P_{\min}$	Minimum water pressure on wall at seabed.
K	Stiffness of equivalent spring.	P_p	Passive soil force per unit length of wall.
K	A constant.	P_{w1}	Average maximum wave pressure on wall at still water level.'
k	Permeability	$P_{h,1}$	Maximum hydrodynamic pressure on wall at still water level.
L	Length of vessel.	P_u	Pore water pressure.
L	Wavelength.	p	Probability.
L_{BP}	Length of vessel between perpendiculars.	p_n	Probability of n th value being equalled or exceeded.
L_0	Wavelength in deep water.	P_{w2}	Average maximum wave pressure on wall at its foot.
L_w	Waterline length of vessel.	P_u	Effective uplift wave pressure at foot of wall.
L'	Overall length of pile from deck to apparent fixity.	q	Proportion of critical damping.
L_F	Fetch length.		
L_s	Submerged length of member.		
l	Length of cylinder.		
l_e	Effective length of anchorage.		
l_0	Ineffective length of anchorage.		

R	Resistance per unit area to shear along soil slip surface.	v^*	Friction velocity.
Re	Reynolds number.	v_c	Velocity of wave propagation.
r	Radius.	v_{cg}	Wave group velocity.
r	Polar coordinate.	v_{cga}	Wave group velocity at arrival point.
$S(f)$	One-dimensional spectral density function.	v_{cg0}	Wave group velocity in deep water.
s	Bed slope (tangent of angle relative to horizontal).	v_{c0}	Velocity of wave propagation in deep water.
T	Wave period.	w_p	Water particle orbit width at surface.
T_0	Period over which observations are taken.	w_F	Fetch width.
T_p	Period at which peak occurs in wave spectrum.	w_s	Width or diameter of submerged structure or member.
T_R	Return period	X_1	Component of radial in direction parallel to mean wind.
T_s	Significant wave period.	x	Rectangular coordinate.
T_z	Zero-crossing wave period.	x_w	Wave prediction parameter.
t	Variable used in normal distribution.	Y_a	Dimension of submerged member.
t	Time variable.	Y_b	Dimension of submerged member.
t_{90}	Time required for 90 % of original bacteria in a sample to die.	Y_c	Dimension of submerged member.
U_w	Wind speed 10 m above sea surface.	y	Variable used in normal distribution.
U	Instantaneous water particle velocity normal to member.		Rectangular coordinate.
U_z	Wind speed at z m above sea surface (other subscripts for different heights).	Z	Tidal lag.
$\dot{U}$	Instantaneous water particle acceleration normal to member.	z	Pile wall thickness.
u	Horizontal component of water particle velocity.	α	Angle of current off bow.
u	Horizontal component of water particle acceleration.	α_r	Angle of wind radial relative to mean wind direction.
V	Incident current velocity.	α_s	Angle of slope from horizontal.
V_B	Velocity of vessel normal to berthing face.	α_0	Angle of wind off bow of vessel.
V_C	Design current speed.	α_c	Angle of current relative to member axis.
V'_C	Average current velocity over mean depth of vessel.	α_1	Coefficient of wave pressure at surface dependent upon wave period.
V_{crit}	Critical current velocity.	α_2	Coefficient of wave pressure at surface due to shoaling.
V_w	Design wind speed.	α_3	Ratio between wave pressures at surface and at depth d' .
V_η	Vertical velocity of water surface.	β	Angle of resultant wind force off bow of vessel.
v	Vertical component of water particle velocity.	β	Angle between direction of wave approach and normal to breakwater.
v_s	Average fall velocity of sediment in still water.	β_0, β_1 and β_{max}	Coefficients used in calculation of significant wave height in surf zone.
v	Vertical component of water particle acceleration.	β_0^*, β_0^* and β_{max}^*	Coefficients used in calculation of maximum wave height in surf zone.

γ	Term in JONSWAP spectral density function.
γ	Effective bulk weight density of soil.
γ_d	Drained bulk weight density of soil.
γ_s	Submerged bulk weight density of soil.
γ_w	Weight density of ground water.
Δ	Logarithmic decrement of structural damping.
δ	Angle of wall friction.
δ_m	Mobilized angle of friction between soil and structure.
$\delta_{\max}$	Maximum angle of friction between soil and structure.
δ_s	Angular ray separation at harbour entrance.
η	Instantaneous height of water surface above still water level.
η^*	Elevation above still water level to which wave pressure is exerted.
θ	Polar coordinate.
θ_0	Angle of incident wave relative to breakwater axis.
κ_J	Coefficient in JONSWAP spectral density function.
κ_P	Coefficient in Pierson-Maskowitz spectral density function.
λ	Term used in wave chart analysis ($= \log_e N_z$)
λ	Coefficient of local wave pressure.
μ	Coefficient of friction.
ν	Kinematic viscosity of water.
π	Ratio of circumference to diameter of circle.
ρ	Mass density of water.
ρ_A	Density of air.
σ	Stress normal to plane of sliding.
τ_0	Shear stress exerted on bed by flowing water.
ϕ	Angle defining wave direction.
ϕ_r	Angle of soil shearing resistance.
ϕ_m	Mean wave direction.
ϕ_0	Offshore wave direction.
ϕ_1	Limiting wave direction (similarly ϕ_2).
ϕ'	Effective angle of soil shearing resistance.

ψ	Angle between wave front and bed contour.
ψ_0	Angle between wave front and bed contour in deep water.
ω	Term in spectral density functions.

Section 2. Environmental considerations

5 General

A fundamental prerequisite to designing a maritime structure is the understanding and assessment of the naturally occurring phenomena to which that structure will be exposed. Information concerning these phenomena may already be available from existing sources; however such data may often be limited in scope and application and further detailed investigations may be required to permit the selection of design parameters and to assess the behaviour or impact of the proposed works on their environment.

This section describes the various environmental phenomena which should be considered for investigation at a coastal site and gives information and guidance on methods of data collection.

6 Survey control

6.1 General. The validity of many measurements undertaken on site is dependent on the accuracy to which they have been positioned and levelled. Whenever possible, investigation work should be related to the established land survey system, which in the UK would be the Ordnance Survey National Grid. Should this not prove possible then a local grid system orientated by azimuth should be established prior to all other site operations, with sufficient permanently monumented survey stations to allow recovery of the survey grid throughout at least the construction time of the structure. It should always be borne in mind that although a simple and relatively inaccurate scheme of survey control may suffice for the purposes of the initial investigations, it may at a later date be required to control other work that is connected with the structure but will demand a much more rigorous approach.

6.2 Level control. Most investigations connected with surveys for maritime structures will require a vertical reference in the form of a water level or tide gauge. Such a gauge should be established as close as practicable to the scene of the investigations, the required degree of closeness being largely dependent on the nature and range of the tide in the locality. Siting of the gauge is important and the following factors should be considered:

- a) the gauge should be in sufficiently deep water to avoid drying out;

- b) it should be sheltered as far as possible from the effect of sea and swell;
- c) it should not be in a position where water is impounded as the tide drops;
- d) it should be reasonably close to a national or local land levelling datum reference point;
- e) it should be sheltered from accidental damage by vessels and should not be mounted or fixed on members which are subject to settlement.

Types of gauges are described in 10.4.

6.3 Location control

6.3.1 General. Various techniques are available for determining the positioning of measurements undertaken over water in relation to the land survey system established ashore. They fall into three broad categories, i.e. visual, radio and electro-optical, with range capabilities extending from a few hundred metres to several hundreds of kilometres. Survey work associated with maritime structures will rarely call for ranging capabilities beyond a few kilometres and it is within this limitation that the following reviews of positioning systems are contained.

6.3.2 Visual methods. Generally the overall accuracy of visual positioning methods decreases with increasing distance and the maximum range for these techniques is approximately 8 km.

Sounding sextants provide probably the most economical means of positioning in situations where distances to coordinated targets are not more than about 4 km and where visibility is not a problem. In experienced hands, sextants can provide a positioning accuracy of ± 3 m or better although such accuracies are unlikely to be obtained at a range of 4 km. It has to be emphasized that accurate sextant work is a skill acquired only through practice and experience and inexperienced observers may produce erroneous results.

Positioning is usually achieved by resection using two horizontal sextant angles, observed simultaneously from the boat, to three coordinated targets ashore. The accuracy of such a fix is governed by the following factors:

- a) the calibration of the sextants;
- b) the observing technique of the observers;
- c) the positioning of the observers relative to the point of measurement: both observers should stand close together and preferably over the point of measurement;
- d) the geometry of the fix;
- e) other "common sense" factors, such as not observing through glass.

A secondary method of positioning by sextant which can be usefully employed in certain situations is the use of a single horizontal sextant angle and transit. Provided that the observer is on the transit, the cut-off angle will provide an accurate measurement of the range to the forward transit target subject to the observation marks being located each side of the transit. The method again calls for skilful technique both on the part of the observer and the boat handler. It is a method which is particularly useful in confined situations and, as a general rule, should not be employed over distances greater than 200 m from the forward transit marker.

Theodolites set up ashore can be used to position a boat offshore by intersection. Although a theodolite can measure to an accuracy of 25 mm as opposed to the sextant's capability of 300 mm, a higher order of positioning accuracy is not necessarily achieved. Lack of synchronism between the shore and afloat elements of the survey work is the main source of error. Use of theodolites also reduces the flexibility of a survey operation since it may be necessary to have frequent changes in the position of the theodolites in order to maintain well conditioned intersections.

6.3.3 Radio-positioning methods. Radio-positioning systems can be broadly divided into three categories, i.e. short, medium, and long range. This review is concerned only with the short range systems which, typically, provide a positioning capability up to 30 km offshore. Some short range systems are capable of ranges in excess of 30 km but this requires very high antennae and/or increased transmitter power.

Short range systems operate in marine radar bands S, C and X which correspond to approximately 3 GHz, 6 GHz and 9 GHz, respectively.

Most operate in a range-range mode, measuring the ranges from two shore reference stations to a mobile master station. The usual update rate is better than one second and accuracies of ± 3 m or better on each range are generally achieved under good conditions.

One X band system is designed to produce position by range and azimuth. Ranging accuracy is similar to the range-range systems. Azimuth accuracy is claimed as better than 600 m. This system is particularly useful in situations where range-range shore reference stations cannot be positioned far enough apart to provide a well conditioned fix or in narrow rivers where the use of range-range systems would involve the setting up of a much larger number of shore reference stations.

A particular feature of all these systems is their overall effectiveness in the inshore situation. They are light and portable and can be installed by relatively unskilled personnel easily and quickly. They are generally very reliable and have low power consumptions allowing them to operate off standard 12 V batteries for several days without attention.

All such systems are essentially line-of-sight systems and thus their effective range is dependent on the height of both shore and mobile station antennae. Heavy rain can attenuate transmitted signals and significantly reduce ranging capability. Reflections from large vessels or shore features can cause gross ranging errors but such situations are usually obvious to the user and can be guarded against.

The short range systems achieve ranging either by phase comparison or by pulsing techniques. In general, phase comparison systems have a better ranging accuracy with ± 1 m possible in good conditions. They are, however, more complex and more expensive. The accuracy of pulsing systems is generally quoted as ± 3 m, which is usually attainable in good operation conditions.

6.3.4 *Electro-optical, infra-red and laser systems.*

Electro-optical, infra-red and laser systems are generally single range measuring instruments developed for land survey and with limited application for survey work afloat. Certain types of electro-optical or laser devices are sometimes useful in situations where it is required to run a survey craft along a line of constant bearing. The instrument is set up ashore or on a fixed structure and the observer in the survey craft can steer visually along the narrow beam produced by the instrument.

Laser instruments have also been developed which can provide a single range from a moving craft to any surface capable of reflecting the laser beam. This type of instrument can be particularly useful for work in confined areas such as docks or close to harbour walls. Range capabilities of existing instruments are presently limited to around 120 m, when using existing reflecting surfaces, but up to 600 m and beyond can be obtained from specially installed retro-reflectors.

7 Meteorology and climatology

7.1 General. This clause describes the meteorological and climatological considerations which should be taken into account during the data collection, design, construction and operational stages of a proposed maritime structure. The type and method of collection of information and some possible formats for the final presentation of data are also outlined.

Authoritative meteorological and climatological data can generally be obtained from the meteorological office covering the area under consideration.

Of particular interest to the construction industry is the quick reply climatological service (CLIMEST) developed by the Meteorological Office, Bracknell, Berkshire, England, to assist tendering and planning in the UK especially in estimating the time likely to be lost because of adverse weather. CLIMEST gives estimates of average monthly and annual values of rainfall, low temperatures and strong winds applicable to the site. The information provided by this service is not generally adequate for detailed planning and a further site-specific data search should be undertaken.

7.2 Wind

7.2.1 General. The constantly maintained temperature difference between the poles and the equator provides the energy supply necessary to drive the planetary atmospheric circulation. This circulation involves both vertical and horizontal movements of air although the average horizontal wind speeds are generally of the order of one hundred times greater than the average vertical speeds. Important exceptions to this rule do occur, for example in convective storms or hurricanes, tropical cyclones or typhoons, for which special structural design is usually indicated in the local codes of practice. Naturally occurring vertical air movement also becomes important in the study of dispersion of chimney and stack emissions and at sites subject to mountain and valley winds or winds affected by major topographic barriers. The predominant controls on the horizontal movement of air near the earth's surface are the pressure gradient force, frictional forces and forces due to the rotation of the earth, i.e. Coriolis and centripetal forces.

Irrespective of long term origin and subsequent modification, the wind at and surrounding a maritime construction site is of great significance to the designer, both for the loads it imposes directly on the structure and for the associated wave heights, wave loading and mooring forces. Loading is discussed in section 5, whilst the forecast of waves from wind measurements is discussed in section 4. With regard to the latter, it is important that wind direction is known so that the fetch can be adequately defined, thereby avoiding the error of forecasting high waves from strong winds blowing off the land.

Long term wind records are particularly necessary for coastal construction for estimating weather windows and likely delays during site investigation, construction and operation. The effect of the wind on water set-up, storm surge generation and coastal up-welling is of importance. Local variations in the wind regime caused by topographic influence should be considered when defining design criteria. In addition, a daily cycle of land and sea breezes may be superimposed on a larger scale wind field. Typical velocities of sea breezes are 4 m/s to 7 m/s and of land breezes only about 2 m/s. The time of observation is thus important and daily readings at say 0900 hours local time may not necessarily give data representative of the full 24 h.

Reliable records of wind speeds and directions are available covering most parts of the world, including the oceans, for a large number of years. Such records should provide adequate information for the derivation of the relevant design parameters, where not already available from local wind-loading codes of practice. Records required should include those relating to:

- a) fetch areas where incident waves could be generated;
- b) cyclone or cyclonic depressions, for correlation with surge occurrences;
- c) typhoon or hurricane tracks and intensities in the vicinity of the site or relevant fetch areas;
- d) wind speeds and directions in the vicinity of the site.

Both maximum gust and average wind speeds should be obtained as well as wind direction (see 7.2.4). Records should be checked to ensure that corrections appropriate to the particular recording station have been applied (see 7.2.3).

7.2.2 Wind sensors

7.2.2.1 General. Wind speed and direction are usually measured by means of some form of anemometer and wind vane. The output may be either recorded or read at regular intervals. The former provides more information, especially regarding the strength and frequency of gusts, and the latter yields only short term averaged readings. Several types of instrument are available as described in 7.2.2.2 to 7.2.2.5. All instruments have advantages and disadvantages and expert advice should be obtained before installation.

7.2.2.2 Cup and vane anemometers. Cup anemometers work on the principle that the rate of rotation of vertically mounted cups is proportional to the wind speed. The output is transmitted either as a series of pulses or as a variable voltage. The former is generally totalized and read daily giving an estimate of the run of the wind. The voltages from both the cups and the wind vane on the latter are either output onto voltmeters and read regularly or recorded continuously.

7.2.2.3 Impeller type. The impeller-type anemometer is similar in function to the cup instrument except that the impeller is mounted horizontally along the axis of the wind vane, resulting in a more compact rugged unit.

7.2.2.4 Pressure type. The pressure-type anemometer consists of a hollow tube, one end of which is open and balanced to face into the wind and the other is connected to a sensitive manometer. The pressure in the tube is directly related to the wind speed.

7.2.2.5 Other types. Many other types of anemometer have been developed, but they are mainly for specialized uses and are not generally considered as field instruments. They include vortex velocity meters, sonic anemometers, hot-wire anemometers and laser-Doppler anemometers.

7.2.3 Exposure and level of measurements. Care should be taken when siting an anemometer since eddies created by obstructions such as trees and buildings may produce unreliable measurements of the wind speed and direction and hence inaccurate estimates of the local wind regime.

In order to allow the comparison of wind records from different locations and heights, measurements should be referred to the standard height of 10 m above ground level. Whenever possible, measurements are made at 10 m or at a greater height to obtain an exposure clear of surrounding obstacles. Each instrument siting should be given an effective height which is defined as the height over open level terrain in the vicinity which, it is estimated, would have the same mean wind speeds as those actually recorded on the anemometer. For comparison with an effective height of 10 m a correction has to be applied which will vary with different averaging time intervals and site conditions and expert advice should be sought before measured values are corrected.

Historically, the smallest time interval which could be identified was 3 s, due to the averaging time of the Dines pressure tube anemograph and thus the concept of the 3 s maximum gust was developed. This gusting interval has been accepted for general structural design purposes and its use is discussed in full in CP 3:Chapter V-2; however gusts at intervals of several milliseconds can now be measured and research may be necessary to define significant gusting intervals for structures which are particularly sensitive to excitation by very short gusts. In particular, the spectral approach has been considered for wind loading due to gusts. For very large vessels which have slow response times, considerably longer gusting intervals will be necessary to develop the full fender and mooring line strains. Further studies may be desirable in order to evaluate the lower design gust speed which will be appropriate in such cases.

7.2.4 Presentation and use of wind data. Standard wind records which are usually stored as hourly mean speed and direction and maximum gust speed, may be used as follows.

- a) As a basis for wave prediction (see Section 4).
- b) To calculate averages and maxima, for example as shown in percentage frequency tables.
- c) To prepare wind roses or similar diagrams which provide a pictorial summary of the frequency distribution of wind direction and speed measurements.

- d) To calculate extreme wind speed values by plotting measured maxima on a probability scale and extrapolating along the line of best fit. A return period or recurrence interval can thus be defined for a given wind speed such that it is likely to be exceeded on the average only once in that period. Data can also be plotted on a linear percentage exceedance diagram to illustrate the probability of a given measured wind speed either being greater or less than a certain limit.

- e) To prepare persistence diagrams to show the expected duration and number of occurrences of particular wind speeds that are likely to be experienced.

7.2.5 Alternative wind information. If no measured wind data are available, the atmospheric pressure distribution may be used to calculate a smoothed picture of the wind field. Such methods are very approximate and are generally only used for weather forecasting and wave prediction. The associated calculations should be carried out by specialists.

7.3 Precipitation

7.3.1 General. The effect, type and intensity of precipitation should be assessed when considering the following aspects of design.

- a) *Drainage design.* Estimates of maximum expected rainfall from a 50 yearly or 100 yearly storm should be made.
- b) *Dead weight loading.* The accretion of snow or ice will exert load on a structure. The amount and expected duration of snowfalls should be considered.
- c) *Cargo handling.* The annual variation in rainfall is important with reference to the type of cargo handled and the storage facilities in a port complex.
- d) *Penetration.* A high frequency of driving rain may necessitate special protection for buildings.
- e) *Construction delays.* Frequent rain will increase construction time substantially, especially earth-moving operations.

7.3.2 Direct point measurement. Rain gauges measure the rainfall over a small known area, historically 19.6 in² for a standard 5 in diameter synoptic gauge and more recently either 150 cm² or 750 cm² depending on the time between inspection of the collected precipitation and the degree of resolution required for measuring small quantities. It is therefore unlikely that the measurements will be directly representative of a larger area due to topographic changes and man-made influences. This has to be considered both during calculations of total available water and in particular whenever historic rain data are used for a purpose other than that for which they were originally collected.

7.3.3 Exposure and measurement. Care has to be taken in the exposure of rain gauges; they are usually located on flat ground with the top of the collecting funnel 0.3 m above the ground and well clear of any obstructions.

The simplest gauges consist of a collector with knife-edged circular rim and a funnel leading into a receiver. The precipitation collected can be measured directly by transfer to a vessel graduated for use with the particular type of gauge and size of collecting area. Alternatively, a recording device can be used such as a tilting siphon or tipping bucket. These gauges generally underestimate rainfall when compared with a standard gauge but can give useful information on time of occurrence and intensity. The rainfall events are generally recorded on clockwork drum charts or on automatic data loggers using a recording medium such as magnetic tape or are telemetered direct to the user, as in flood warning networks, for example.

7.3.4 Water balance. Where it is impractical to install a rain gauge network it may be possible to calculate the rainfall by considering the total water budget of a catchment including river flow rates, evapotranspiration and infiltration measurements.

7.3.5 Historic data. Authoritative rainfall data may be obtained from the local meteorological office or from local water authorities, although some calculations may be necessary before the information can be applied to any particular site.

7.4 Air temperature and humidity

7.4.1 General. Estimates should be made of minimum and maximum air temperatures and the variations in relative humidity which are likely to be encountered during the life of the structure.

7.4.2 Air temperature. To provide suitable design data four temperatures should be measured at regular intervals, i.e. minimum and maximum, and wet and dry bulb. The thermometers should be exposed inside a Stevenson screen with the bulbs at 1.25 m above the ground.

7.4.3 Relative humidity. This is defined as the actual water vapour pressure expressed as a percentage of the saturated water vapour pressure at the same temperature. It is a measure of the dampness of the air and is important in cargo storage and in certain aspects of building construction, particularly concrete curing. Relative humidity is calculated from wet and dry bulb temperatures or can be measured directly using hygroscopic material.

7.4.4 Historic data. Information on averages and extremes of daily, seasonal and annual temperatures and relative humidity may be obtained from the local meteorological office or in published tables for selected sites.

7.5 Visibility

7.5.1 General. Poor visibility may have severe consequences in inshore waters and estimates of the expected duration should be made. The reduction of atmospheric transparency and hence visibility is caused by two predominant factors:

- a) a suspension of extremely small dry particles, called haze;
- b) suspended microscopic water droplets or wet hygroscopic particles, known as mist.

Fog is a term conventionally applied when the horizontal visibility at the earth's surface is reduced to less than 1 km.

7.5.2 Measurement. The method of measurement generally employed for synoptic purposes is the observation of objects at known distances, for example conspicuous trees, church towers, surrounding high land or, at night, lights specially erected for the purpose.

Visibility, in common with many other meteorological variables, often changes sharply near the coast between the widely different regions of sea and land. At coastal stations of the UK Meteorological Office, however, the visibility over the land is recorded as standard even if this is different from the visibility over the sea. The latter is recorded as a remark if it can be estimated. Caution should be used when studying visibility reports from a station not directly on the coast as the phenomenon known as sea fog may not be experienced more than 3 km to 4 km inland and erroneous data can therefore be extracted for navigation and piloting purposes.

Recent research has been conducted into the automatic measurement of visibility to remove observer bias and provide an input for unattended measuring stations. Techniques investigated include measuring the attenuation of a light source of known output over a prescribed distance and the amount of back scatter from a light source, but no single method has proved successful for all applications.

7.6 Atmospheric pressure

7.6.1 General. The pressure of the atmosphere at any point is the weight of the air which lies vertically above a unit area. The atmospheric pressure is recorded in millibars¹⁾ and is generally corrected to mean sea level, to remove the influence of altitude on the measurements.

The pressure distribution is used as a basic input parameter in the preparation of weather, and hence sea state, forecasts. In particular, the influence of pressure on water level is of importance. A high or low pressure will decrease or increase, respectively, the depth of water to cause what is known as a storm surge, either negative or positive (see clause 10).

7.6.2 Measurement

7.6.2.1 General. The techniques described in 7.6.2.2 to 7.6.2.4 may be employed.

7.6.2.2 Mercury barometer. The pressure of the atmosphere is balanced against the weight of a column of mercury. The two main types are the Fortin and the Kew-pattern barometers.

7.6.2.3 Aneroid barometer. An aneroid barometer consists of one or more thin metal capsules, partially evacuated of air. The change in the thickness of the capsules is magnified and typically represented by a needle and dial. Precision aneroid barometers are sensitive to 0.1 mbar with an overall accuracy of ± 0.3 mbar.

7.6.2.4 Barograph. Standard barographs are aneroid instruments. The variation in pressure alters the shape of the sensor and this change is magnified through a system of pivots and levers. The pressure is recorded continuously on a chart secured to a clock drum.

7.7 Solar radiation and hours of sunshine

7.7.1 Measurement. The intensity of solar radiation is usually measured with radiometers using a thermopile element which generates a millivolt signal output which can be directly related to the energy received at the sensor. Radiometers can be designed to be sensitive in particular wavelengths of interest, for example incoming short wavelengths or outgoing long wavelengths or in the specific bands of ultra-violet or infra-red.

The duration of bright sunshine is generally defined and recorded by the length of the burn or burns produced by focussing the sun's rays on to a special card and reported as hours of sunshine.

7.7.2 Uses. The incoming, reflected and emitted radiation is of prime importance in thermal balance equations and can be used to estimate the cooling capacity of an area of water and the potential evaporation.

The life expectancy of bacteria released to the sea is thought to be highly dependent on the intensity of solar radiation particularly in the ultra-violet wavelengths. The calculation or measurement of this mortality is important in sea outfall design for effluents such as domestic sewage. The effect of light intensity on marine fouling is well illustrated by the vertical sequence of species found with changing depth on immersed structures.

8 Bathymetry and topography

8.1 General. Bathymetric surveys are produced by taking a series of measurements of water depth at known locations over the area of interest. Information on the various techniques available and guidance on their application to maritime engineering is given in this clause. Guidance on location control is given in clause 6.

Published bathymetric charts provide the designer with very limited data for his purposes. Charts are produced for safe navigation and features which may be of particular significance to the engineer may not necessarily be shown. Charts are only as accurate as the data from which they were compiled. Very often much data will have been taken from old surveys not conducted to modern standards or at scales not suited to modern requirements. Possible changes due to siltation, dredging, dumping, shipwrecks or other causes should be considered and proving surveys should be carried out to check existing charts where there is any doubt as to their reliability.

¹⁾ 1 mbar = 100 N/m² = 100 Pa

1 000 mbar $\approx$ 29.5 inHg

8.2 Echo sounder

8.2.1 General. The prime method of measuring water depth is by echo sounder, which will record a continuous profile of the seabed as the survey craft moves over it. Only purpose-built hydrographic echo sounders should be used if accuracies acceptable for engineering purposes are to be obtained. The typical hydrographic echo sounder will produce a large scale paper trace providing a permanent graphic analogue record of the seabed profile. The instrument will be fitted with a range of controls to enable the operator to adjust and calibrate it to suit the conditions in which it is operating and built to a specification that enables it to maintain reliable and accurate recordings. Echo sounders can give misleading results in areas of very soft mud which sometimes occur in estuaries and in these cases other methods should be used, depending on the application.

8.2.2 Calibration. The echo sounder measures depth by sending out a short ultrasonic pulse of sound and measuring the time taken for this pulse to reach the seabed and be reflected back to its source. The accuracy of depth measurement therefore is dependent on the allowance made for sound velocity through the water.

Calibration is normally effected by lowering a target to a set depth below the sound source, i.e. the transducer, of the echo sounder and comparing the recorded depth against the actual measured depth of the target. The echo sounder can then be adjusted to record true depth. This method, commonly known as a bar check, is effective for calibration down to depths of about 20 m.

Calibration should be checked using the bar in the area of survey and at intervals throughout a working day as both sound velocities and functioning of the echo sounder itself are subject to fluctuations with time and position.

8.2.3 Transmission frequencies. The capability of an echo sounder is much affected by the transmitted frequency. Low frequencies transmit energy efficiently over long distances and will often penetrate through soft seabed materials, producing echoes off underlying strata.

Low frequency equipment, however, generates wide beam widths (see 8.2.4) and is of necessity large and cumbersome. High frequency transmissions can be generated with narrow beam widths from light compact equipment. However, energy is not so efficiently transmitted, being quickly reduced in water, and not generally capable of penetration into the seabed.

Hydrographic echo sounders designed for use in shallow to medium water depths operate typically at a compromise frequency of around 30 kHz. Higher frequency echo sounders operating at between 150 kHz and about 210 kHz are also used and are useful in shallow water. Some echo sounders operate on dual frequencies of say, 33 kHz and 210 kHz, thus combining penetration through very soft sediments with an identification of the depths of these upper sediments themselves.

8.2.4 Beam width. The echo sounder transducer generates a beam of acoustic energy which will cover the seabed over an area dependent on the beam width and the depth. Thus, with a narrow beam width less seabed is covered but definition of seabed features is better. A high frequency, narrow beam width echo sounder would be particularly useful when it is required to obtain details of a rocky, precipitous seabed. This benefit is of course largely lost if the survey craft itself is pitching or rolling. On the other hand, a wider beam, lower frequency echo sounder would be better in flat or gently undulating seabed conditions, providing greater coverage with the additional benefit of some penetration of very soft sediments.

Beam width is not directly dependent on frequency, but on the design of the transducer. It is much easier and cheaper to design and build narrow beam transducers operating on high frequencies than low frequencies. However, not all high frequency echo sounders necessarily generate narrow beam widths and manufacturers' specifications need to be consulted.

8.3 Side-scan sonar. Working on the same basic principles as an echo sounder, side-scan sonar systems transmit a fanshaped beam of acoustic energy perpendicular to the track of the survey craft. The reflected signals from rock outcrops, sand waves, pipelines and any other projections on the seabed are recorded as changes in density on the continuous paper roll record produced. Changes in the nature of the seabed materials may also be detected.

Side-scan systems can be either hull mounted or towed, the advantage of the latter method being that the sound source is closer to the seabed, enabling changes in seabed texture to be determined more easily and the transducer is partly decoupled from the ship's motion. A hull-mounted system has the advantage that there is less chance of damage to the equipment and in inshore waters is generally adequate for locating rock outcrops and underwater obstructions and the position of the transducer is known more precisely.

Although some indication of bathymetric changes can be gained from analysis of the side-scan records, it is essentially a search device. Complete coverage of the seabed by echo sounder would usually involve an excessive amount of work and is not generally justifiable. Use of side-scan sonar enables the surveyor to examine the entire seabed between sounding profiles and to run additional profiles where side-scan records show significant changes in the bathymetry taking place. Side-scan sonar systems operate typically at 50 kHz to 100 kHz with a range capability of up to 400 m on each side of the vessel track.

8.4 Direct measurement. Direct measurements are occasionally required when the echo sounder records are doubted. This can occur when sounding over a particularly soft seabed or when large quantities of weed or kelp are present. It might also be necessary when establishing the least depth over a rock or obstruction. Such measurements are usually made by hand leadline, graduated pole or sweeping with a horizontal wire (see 8.6).

8.5 Spacing and direction of sounding profiles.

The appropriate spacing of sounding profiles will depend partly on the purpose of the survey and partly on the depth and nature of the seabed.

Where the bathymetric information is required for the study of wave and current effects or for the study of navigation channels where the average depth is greater than 1.5 times the draught of the largest ship expected, a chart scale of the order of 1 : 10 000 is generally sufficient. Lines of soundings should be spaced at about 100 m intervals with a locational fix spacing not greater than 300 m.

Surveys required for the study of wave effects should cover the transitional zone relative to the wave periods expected at the site.

For navigation channels, sweeping surveys may be considered as an alternative to detailed sounding surveys where the depth is greater than 1.2 times maximum draught (see 8.6).

In rock and coral areas, more detailed surveys are advisable for navigation channels if the average depth is less than twice the maximum draught of the ship.

Where the bathymetric information is required for the siting of structures, measurement of dredging and checking navigation channels in shallow water, a detailed survey should be carried out to produce a chart to a scale of between 1 : 500 and 1 : 1 500.

Typically, a survey for a maritime structure would be made at a profile spacing of 10 m to 25 m in and around the proposed position of the structure and 50 m in the approach areas with locational fixes taken at approximately three times the profile spacing. Side-scan sonar could be used in conjunction with the echo sounder to obtain a qualitative record of the seabed between profiles, revealing any features undetected by the sounder.

The direction in which profiles are run is again dependent on the purpose of the survey. The usual purpose is to delineate depth contours as accurately as possible. This is achieved by running across the anticipated contours as near as possible at right angles. It is good survey practice to run additional profiles at right angles to the chosen direction at a wider spacing, for example 5 to 10 times. These lines will serve the purpose of check lines and also reveal the presence of features such as sand waves which, because of the original choice of direction, may not have been identified.

8.6 Wire sweep. A wire sweep survey may be necessary for determining the least depth over an obstruction or to prove the absence of obstructions in a particular area.

The former can be achieved by suspending a horizontal bar fore and aft from the vessel, which drifts over the known obstruction. After each pass, the bar is lowered or raised by its calibrated support wires and, by noting the bar's depth setting and applying the tide correction, the least depth over the obstruction can be determined.

As an alternative to side-scan sonar, for ensuring an area free of underwater obstruction, a fine-wire sweep survey can be conducted. The fine wire is suspended between two boats and weighted to maintain a predetermined depth. The boats proceed at 1 m/s to 1.5 m/s (2 knots to 3 knots) along the necessary course lines to ensure full sweep coverage of the area.

8.7 Reduction of soundings. Due to the vertical movement of the water level, soundings obtained have to be reduced to a standard reference plane by subtracting the actual height of the water level above this plane at the time of sounding. The rise and fall of the water level is observed on a tide pole or tide gauge during the sounding operation and heights plotted against time. This gauge should be as close to the area as possible. From the curve showing the variations in water level, soundings can be reduced to a suitable reference plane or datum (see also clause 10).

Care should be exercised to ensure that soundings are recorded in synchronism with the tide readings. This is most important where a high rise and fall is expected.

8.8 Coastal topography. Depending on the survey area and the scale of presentation, the final bathymetric plan should portray the coastline and prominent features, in order to allow immediate visual recognition.

It is general practice to show the high and low water contours on bathymetric charts. Should the bathymetry be conducted over the high water period it is usually possible to determine the low water contour from the sounding results. To obtain the high water contour it would be necessary to carry out levelling, by land survey practice, over the area not already covered during the sounding operation.

Although the bathymetric survey may initially be required only for navigational or wave study requirements, the results of many inshore bathymetric surveys may subsequently be used for structural planning purposes in conjunction with the results of the local land-based topographical survey.

Therefore the bathymetric plan should preferably be plotted on the same grid system as the land survey and the relationship between the vertical reference planes of each should be clearly recorded (see clause 6).

9 Geotechnology

A thorough understanding of subsurface conditions is an essential preliminary in any maritime construction project. Section 6 includes guidance on the type and extent of geotechnical studies required, including geological, geomorphological and geophysical aspects.

10 Water level

10.1 General. The underlying long-period fluctuations in general water level result from astronomical tides which are generated primarily by the cyclic variations in gravitational attraction of the moon and the sun on the water masses of the earth. Superimposed shorter period fluctuations and non-periodic variations may be caused by such factors as wind, atmospheric pressure, wave effects, local run-off and evaporation. Tidal ranges vary widely around the world and are affected by geographical factors. The shallow waters surrounding the British Isles have the effect of increasing the height of the tidal wave considerably; in the Severn estuary ranges can exceed 15 m. Tidal ranges in the open ocean, however, are often less than 1 m.

Predictions of extreme water levels are required in several aspects of the design of maritime structures, including overtopping, hydrostatic pressures and the level of action of waves, currents, mooring and berthing loads. Values of rates of rise and fall may also be required in relation to soil pore water pressures, flood relief valve discharge capacities and for the prediction of tidal flows.

10.2 Tidal predictions. Admiralty Tide Tables list daily predictions of times and heights of high and low waters at a selected number of standard ports [1]. These predictions are of universal application and are usually based on continuous observations of the tide over a period of at least 1 year at that standard port. The tables also list data for secondary ports, enabling predictions to be calculated from the predictions listed for standard ports.

Tide tables and almanacs are also published by harbour authorities and others. It should be noted that whereas Admiralty Tide Tables give heights referred to chart datum, i.e. the datum of soundings on the latest edition of the largest scale Admiralty chart, it is not unusual for locally produced tide tables to be based on a different datum. Certain commercial companies also offer tide prediction services.

NOTE Commercial and harbour authorities often obtain their predictions from the Institute of Oceanographic Sciences, Bidston, Birkenhead, England when information is required in a more detailed or specific format than that required for the Admiralty Tide Tables.

10.3 Meteorological effects

10.3.1 General. Tide predictions are based on average meteorological conditions. Variations in predicted heights will occur with changes in the meteorological regime. The main effects are described in 10.3.2 to 10.3.5.

10.3.2 Atmospheric pressure. Changes in level due to variations in atmospheric pressure seldom exceed 0.3 m. However, when combined with other effects such as strong winds and intensified by geographical constrictions, this effect can be important.

10.3.3 Wind. A strong wind blowing on shore will tend to pile up water against the coast, resulting in a water level higher than the predicted tide height. Winds blowing along a coast tend to set up long waves which travel along the coast raising the sea level at the crest and lowering the sea level in the trough. Grouping of waves from distant storms can produce variations of mean sea level within the group, resulting in a long period, low amplitude wave travelling at the same velocity as the group, which, when it approaches the shore, can cause a higher sea level and thus allow the waves to run further inshore before they break. A combination of pressure and wind effects can cause the phenomenon known as a “storm surge”.

10.3.4 Seiche. The passage of an intense depression may cause oscillations in sea level. The period between such waves may be anything from a few minutes to 2 h and the height from a few centimetres to 2 m to 3 m. The shape, size and depth of some harbours makes them very susceptible to such waves, increasing their height often to destructive proportions.

10.3.5 Water levels. Water levels in estuaries may be raised by river flow originating from surface water run-off or artesian sources. Special factors such as opening of sluice gates upstream and seasonal flow patterns should also be considered.

10.4 Tidal observations

10.4.1 General. Where predictions are not already available, records of the water level should be taken at the proposed site over the minimum period discussed in 10.5. Various methods of automatic tide recording are available (see 10.4.2). The apparatus should filter out, by means of a stilling well or other means, short period level fluctuations due to wind or wash waves.

Even in situations where predictions are already available, a permanent tide gauge is necessary to provide a reference for other data-gathering operations (see 6.2).

10.4.2 Types of gauge

10.4.2.1 General. The types of gauge described in 10.4.2.2 to 10.4.2.8 may be considered. With the exception of 10.4.2.2 all are automatic.

10.4.2.2 Tide pole or staff. The tide pole or staff is a simple graduated pole set up vertically in the water so that the changing level of the sea surface may be read on it. A tide pole should always be installed where possible, regardless of any other automatic gauge which might also be deployed. It provides a calibration and checking standard for automatic gauges.

10.4.2.3 Float operated. A float installed in a specially designed vertical stilling well is connected directly to a chart recorded by a wire. Careful installation of this system can be rewarded by excellent tidal records.

10.4.2.4 Pressure operated. The height of the tide exerts pressure on a submerged diaphragm which actuates a recording mechanism. Such systems can be connected to a surface recorder using an air-filled tube or the whole system can be a bottom-mounted unit, the latter being also used offshore. Electronically controlled pressure transducer systems are also available and are very satisfactory, particularly for long term use where a power supply is available.

10.4.2.5 Bubbler gauge. A constant flow of compressed air is released via a bubble chamber, to an open-ended tube set at a known depth below LAT. The pressure of the water head above the open tube will vary with the tide and thus alter the pressure in the bubble chamber. This latter pressure variation can be recorded on a drum chart.

10.4.2.6 Electrical capacitance gauge. An electrical capacitance gauge system uses the varying electrical capacitance of a wire mounted vertically in the intertidal zone. Care has to be taken in areas of changing salinity for corrections in the conductivity of the sea water.

10.4.2.7 Electrical resistance gauge. An electrical resistance gauge is a similar system to the capacitance gauge, which uses the changing resistance between two parallel electrical wires to determine water level.

10.4.2.8 Inverted echo sounder. An echo sounder is laid on the seabed and transmits towards the surface. A continuous record of the water level is obtained. Care should be taken to prevent movement or burial of the transducer. Ultrasonics can also be used by locating the transducer above the water level.

10.5 Tidal analysis. If a sufficiently large data base is obtained, an analysis of the records can produce the astronomic tidal harmonic constituents which may then be used to predict astronomic tidal heights for the future. These predictions assume that no other changes occur at the relevant site and their accuracy depends on the size and accuracy of the original data base. It is possible to obtain the basic harmonic constituents for a site from only 11 days' tidal data but this requires favourable circumstances. Continuous records covering 28 days to 30 days will give a much more reliable analysis and subsequent predictions. A full tidal analysis from a minimum of 1 year's continuous data can produce up to 110 tidal constituents which can be used to predict accurate astronomical tidal heights.

Such analyses and predictions are explained in detail elsewhere [2]. It has to be stressed that predictions can only give astronomic tidal heights and that actual water levels can differ significantly due to meteorological effects (see 10.3).

11 Water movement

11.1 General. The largest scale global water movements are the essentially permanent ocean currents. These currents are the result of the response of the ocean and atmosphere to the global distribution of solar energy and the resultant flow of energy from the tropics to the poles. The surface ocean current systems correspond quite closely to the generalized global atmospheric circulation and shift seasonally with the passage of the overhead sun. Good local descriptions of these basic water movements can be found in the Admiralty Pilots series of publications [3].

Surface ocean currents have been well documented for over a hundred years because of their significant influence on navigation and trade. The deeper currents and counter currents, however, are relatively modern discoveries following the invention of reliable oceanographic instruments, such as current meters. The use of water sample bottles and in situ temperature measuring devices, such as the reversing thermometer, also considerably aided study of the deep ocean water masses as temperature and salinity provide useful identifiers of place of origin.

In the open ocean, the wind blowing over the seas induces a current in the surface water layer which moves at an angle of approximately 45° to that of the wind, to the right in the northern hemisphere and to the left in the southern. Due to the Coriolis effect on successively deeper layers of water, the resulting net wind-induced mass movement is similarly directed to the right or left but at 90° to the direction of the original wind. In sea areas adjacent to a land mass, prevailing winds blowing parallel to the coast can produce vertical water movement known as upwelling and downwelling or sinking. Short term wind systems of the order of 2 days' or 3 days' life can induce horizontal currents which may reach a speed of 0.5 m/s (1 knot) in a prolonged strong gale. These currents are difficult to predict as they take some time to develop and may continue to run for some time after the wind has dropped. As a general rule, these wind-induced currents tend to flow at a rate of 2 % to 3 % of the speed of the wind which set them in motion. Water currents associated with storm surges can move with the speed of tide-generated currents and are thought to be due to a combination of direct wind influence, the motion of the surge generating depressions and differences in sea level associated with the atmospheric pressure gradient (see clause 10). This latter current component is an example of a slope current caused by the response of the water surface to either increased or decreased atmospheric pressure. In theory this response is equal to 10 mm for each 1 mbar change of pressure but in temperate latitudes the atmospheric pressure distribution changes so rapidly with the passage of depressions that the predicted steady state relationship can only be attained infrequently. Slope currents can also be generated by wind set-up, wave set-up or horizontal changes in temperature or salinity, causing variations in seawater density, i.e. density currents. Geostrophic or earth-turned currents can result from a sloping sea surface, created by wind or density, and the balance between the effect of gravity and deflection due to the Coriolis effect.

Water movements of purely astronomical origin are conventionally known as tidal streams. In practice, the total water movement in an area is a combination of the generally predictable ocean currents and tidal streams, with shorter term local wind- or pressure-induced currents and, in shallow water, wave-induced currents. Tidal streams in European waters are generally of the same type as the tides, namely semi-diurnal. In other parts of the world, however, the pattern of tidal streams can be entirely unrelated to the pattern of the tides and independent predictions are necessary. Tidal streams around the British Isles are shown in pictorial form in the atlases published by the Hydrographer of the Navy and include permanent estuary currents due to river flow [4]. In the absence of alternative information, in areas of semi-diurnal tides the tidal streams experienced during a spring tidal range may be considered as being twice as strong as those occurring during a neap range.

For a fixed structure in coastal water, the parameters of water movements important for design are the speed and direction of water movement at a point and how this will be affected when the water impinges on the structure. The permeability of the structure, its resistances to motion and the possibility of sediment scour or accretion should be considered. However, for the discharge of a liquid or solid effluent and its removal from an area of dilution within it, the water movement pattern over a much wider region may have to be determined.

Water movement on a scale larger than a particular water parcel, which tends to transport the water rather than mix it, is known by the term advection, i.e. due to currents. The terms diffusion or mixing are used to describe water motions of the same size or smaller than the particular water parcel. The smallest scale motions known as molecular diffusion can generally be ignored in this context as they are inefficient compared with the larger scale motions defined as eddy or turbulent diffusion. The distinction between advection and diffusion can also be demonstrated by averaging water movement over an area. The advection will be the net movement on which is superimposed a fluctuating flow consisting of equal and opposite exchange flows, the diffusion.

11.2 Measurement of advection

11.2.1 General. Indirect methods of calculating water movement are generally not suitable for inshore work and direct methods of measurement should be used. These methods rely upon either measuring the velocity of water at fixed points, for example by current metering, or following the trajectory of a labelled water parcel, for example by float or dye tracking.

11.2.2 Current meter observations

11.2.2.1 General. Although this method of measurement provides a direct reading of current speed, its application to mass transport in coastal waters is restricted because observations made at one point cannot be assumed to be representative of a larger area. Other limitations are practical ones, for example low current speeds may be beneath the threshold of the instrument and transmitted vessel or moorings movement may have a significant effect on the readings.

The operational principles of the many types of meter available are described in **11.2.2.2** and **11.2.2.3**.

11.2.2.2 Direct reading current meters. Direct reading current meters are operated, usually manually but occasionally via a telemetry link, from a moored vessel or existing structure. Water speed is generally calculated from a count made of the number of revolutions of an impeller or Savonius rotor during an accurately measured time interval. Horizontally mounted propeller or cup assemblies have been used as the revolving element but were generally found to be more fragile. Current direction is measured by the alignment of the hull of the meter or vanes relative to an internally housed, free moving compass card. Care has to be taken in operating current meters in the presence of waves, due to transmitted boat and suspension gear movement and wave action on the meter itself. In particular, the Savonius rotor instruments tend to over-register speed under wave influence because of their omnidirectional response. Using one relatively cheap instrument, it is possible to obtain rapidly a detailed velocity profile of the water column by lowering the instrument from near surface to near bed and making measurements at several intermediate levels.

11.2.2.3 Recording current meters. Recording current meters are typically between 2 and 10 times more expensive than the direct reading current meters and record the velocity internally on a medium such as magnetic tape, photographic film or solid state memory. There is thus no requirement for constant vessel and operator attendance and good moorings should enable data to be collected under worse sea conditions than would be possible by an instrument suspended from a floating craft. Traditionally the recording current meters measure speed with either an impeller or Savonius rotor and record the number of revolutions during intervals of typically 5 min, 10 min, 15 min or 30 min, hence obtaining an average water speed over each sample period. In theory the instrument is permanently aligned with the direction of water movement by one or more large vanes and the instantaneous direction held at the end of a sample interval is recorded. In practice, however, wave orbital motions will affect speed and direction measurements made by the traditional type of current meter. In order to measure such short period motions, other types of equipment have been developed which resolve the current into two perpendicular directions so that measurements of direction are independent of the orientation of the meter. Two of the most widely used are electromagnetic and acoustic current meters. The former measure changes in an induced magnetic field and the latter the apparent variations in the speed of sound due to the water movement. Generally these meters will measure the current velocity at frequent intervals, for example 1 or 10 times a second, and either record a burst of data, for example 10 min every hour, or perform a vector average to remove the orbital currents before recording.

11.2.3 Float tracking. This method of tracing water movement involves the introduction of readily identifiable material which moves with the water, thus directly indicating its path. The size and shape of the floating object affects its reaction to the surrounding water movement and hence whether it faithfully follows that movement. The standard float assembly consists of a vaned drogue usually made out of canvas, wood, metal or plastics, joined by thin rope or wire to a surface buoy. The length of rope determines the depth of water at which the drogue will lie and follow the water motion. The drogue is typically 0.5 m to 1.0 m long and, when suspended at a depth of say 2 m, its path will be an expression of the average horizontal movement of a water parcel between 2 m and 3 m below the surface.

A major problem with float tracking is relocation. A large surface buoy or marker such as a flag or radar reflector will be subject to windage and, in the case of a buoy, to influence from the surface water currents in which it is floating. These top marks should therefore be kept as small as possible consistent with the need for good visibility. In order to aid relocation, small radio transmitters or underwater acoustic devices can be used together with radio direction finding antennae or acoustic receivers. Location by sonar has the advantage that the surface float can be smaller. These devices are most useful in the dark and easier to find than the flashing lights previously employed. Methods have been developed to remove the windage influence from the resultant track of a float but further work is necessary before the techniques are widely adopted.

A logship is a particular design of float used to show average horizontal motion over a greater depth of water, such as 6 m to 10 m. It consists of a long thin member with identification on one end and weights at the other so that it will float vertically just under the water surface. Typical materials used are telegraph poles, tree trunks, bamboo poles or lengths of aluminium. Logships are particularly useful in navigation studies and harbour layout planning since their lengths can be adjusted to be representative of the relevant vessel draught.

Floats can also be used to obtain point-specific information by releasing them at the bows of a moored vessel and timing their passage over the known distance to the stern. Alternatively, floats attached to an anchored vessel by a known length of floating cord can be allowed to drift astern. The velocity can be calculated from the time for the float to run to the end of its tether and the current direction can be found by taking the bearing of the float. In both of these applications it is likely that the presence of the vessel will modify the current speed and direction and hence float path. A crude estimate of current velocity can be obtained from the log reading and compass heading of a vessel moored so that it is free to lie with the current.

The standard drogue float can be modified to follow surface water movement by reducing the length of rope between the drogue and the top mark so that the top of the vane assembly is just on the sea surface. To follow movement in the top 100 mm or to estimate the true path of a surface phenomenon such as a grease or oil film, however, specially designed surface floats should be used. These can consist of disc shapes or spheres which float on the surface, neutrally buoyant bottles, cards or even finely chopped vegetables. A major problem is relocation and it is usually advisable to keep the floats constantly in sight. Aerial tracking and/or photography can provide a useful method of recording float positions but is too expensive for most applications. Drogues with visible top marks can be used to indicate the approximate position of the surface floats but these may not be entirely reliable due to differences between the paths of the identified water layers.

As stated above, the floats will not follow the same turbulent flow paths as the water itself and so will only indicate the average horizontal movement. Another limitation of float track information is the portrayal of a linear picture of water movement with no areal extent. However, float tracking can give a rapid and relatively cheap impression of general water movement. Several floats can be followed at any one time with repeated releases from one position, or multiple releases with drogues set at different depths. Tidal residuals can easily be determined by tracking a float over a complete tidal cycle and determining the distance between its release and recovery positions.

Floats can be deployed unattended if a net movement is required rather than knowledge of the path taken to arrive at the end point. Commonly the floats have messages attached asking the finder to record the time and place of the float recovery and to return the information. To reduce the chance element of the recovery beach-walkers can be employed to search for the landed floats. Similar methods can be used to tag bottom currents when boat following is impossible without, for example, acoustic links. The method can only yield minimum possible water speeds, as without other valid information it has to be assumed that the float took the shortest distance between the points of release and recovery and that the float was recovered as soon as it arrived at its final location.

11.3 Measurement of diffusion

11.3.1 General. Much research over the past 20 years has been carried out to develop various methods of tracing water movement, in particular for the disposal of effluent into the sea where the rate and extent of dispersion together with mass transport are important criteria. An indicator was sought with physical properties similar to those of the water to be labelled. Acceptable techniques which were developed were the use of dyes, radioactive materials and bacterial organisms. These techniques all have specific advantages and limitations and a problem can often best be solved by a combination of two or even three methods but before resorting to any form of artificial indicator, consideration should be given to the use of natural tracers or those not specifically introduced, as described in **11.3.2**.

Artificial or added tracers can be used to label an existing water body such as sewage or process water discharge or to indicate water movement in an area which is being considered as a receiver for an effluent. In the first case, the existing discharge position can often be identified and the tracer can be injected at this location. For example, an effluent could be labelled by the addition of the tracer at the final pumping station or collection point and, with either natural or artificially induced mixing, the total discharge would be tagged before it reached the sea. This is particularly valuable with diffuser outlets as their efficiency in initial dilution can be estimated. The tracer can be added as a single batch, in repeated discrete batches or continuously, depending on the mode of effluent discharge, the tracing facilities and the aim of the study.

Artificial tracers are probably most useful for estimating dispersion rates and mass movement for a proposed discharge at sea before construction. The timing of the release can be organized as considered above although, because of its lower cost, the repeated discrete batch technique is often used for initial studies, such as determining the optimum location and length for an outfall. Provided that the pattern of circulation is steady or repeated regularly under tidal oscillations, the dispersion from a continuous effluent source can be calculated by integration of the results obtained from repeated batch injections of tracer. Alternatively, the batch releases can be used to provide a summary of the water movement and indicate the most important or critical period for effluent discharge and a continuous release can be made over that period for confirmation. For example, the minimum time or distance of travel to the land and the corresponding effluent concentration on the shoreline may be of special interest.

In theory the tracer can be prepared at the same density as the proposed effluent and released at the same level, usually close to seabed, but unless volume flows are also reproduced density effects can still produce misleading results. Ideally the tracer should be introduced over the large area achieved by initial dilution processes and thereafter initial dilution should be ignored. Point sources can, however, be used to give conservative estimates of maximum concentrations of effluent after dispersion.

Batch releases of dye or radioactive isotopes can best be traced by a vessel keeping them constantly under surveillance and traversing the patch at frequent intervals, recording the tracer concentration and simultaneously fixing its position. The patch can be crossed and recrossed in zig-zag fashion, commencing and terminating when the detectors show zero tracer concentration above background. It should be remembered with dye tracing that the boundaries thus recorded will be wider than those estimated visually since the sensitivity of the measuring instruments is greater than that of the eye. Continuous releases cannot generally be sufficiently accurately followed by repeated crossing of the dye patch because of their wide spread, although an attempt should be made to outline plume dimensions. Alternatively, or in addition, a regular grid within the area of expected travel can be sampled or if sufficient craft are available they can moor at separate locations and measure the change of concentration with time at these fixed points. This technique can be extended by recovering samples for subsequent analysis if there are insufficient measuring instruments available. Grid sampling is the only method for use with bacterial tracing, as lengthy laboratory procedures are required before the number of organisms present can be determined.

Measurements of dye concentration and radiation levels can easily be made at any depth, by either lowering the detector or raising a sample of water. Alternatively, towed multi-level arrays can provide simultaneous measurement of dye concentration or radiation levels at several depths. Samples for bacterial testing can also be collected at depth but extreme care has to be taken to avoid contamination. Sealed sterilized bottles are lowered to the required depth, opened to take the sample and resealed to avoid transfer of water to or from the bottle on the return journey.

Although many studies of water movement have been carried out and documented, there are insufficient data available at present to provide a detailed model of either water mixing in coastal areas or more particularly of effluent mixing and dispersion, and this has hindered the cross-transfer and application of documented survey results. Neither is there sufficient information available to define exactly the role of the various physical parameters in determining the mixing rates. This has necessitated the continuation of the practice of carrying out specific site studies, particularly in areas of complicated bathymetry and current regime.

11.3.2 Natural tracers. Tracers are defined here as natural or normally occurring if they can be found in an area before any phase of new construction or site investigation is undertaken. For example, a river discharging into an area would create a particular salinity distribution and the freshwater plume could be traced rapidly using an in situ salinometer. Effluent from existing constructions may contain elements whose redistribution could be used as indicators of local water movement patterns. It may also be possible to evaluate distribution patterns of turbidity, silica and dissolved oxygen or the distribution of certain biological matter such as species of plankton, fish eggs or bacteria.

The discharge of domestic sewage presents an example of an existing controlled release of effluent which can be monitored to demonstrate present dispersion patterns or to assess the capacity of the receiving waters for further discharge. However, problems exist over the choice of indicator.

Biochemical oxygen demand, dissolved oxygen concentration and nutrient load, for example, nitrogen or phosphorus concentrations, have been considered as tracers but as a generalization a bacteriological indicator such as *Escherichia coli* appears to be the most satisfactory for temperate latitudes. *E. coli* organisms are natural inhabitants of the intestine and are present in large numbers in domestic sewage, approximately 10^6 organisms per millilitre of untreated sewage being a typical count in the British Isles. Unfortunately, *E. coli* is not a specific identifier of a particular discharge as it may enter the sea via rivers, seabirds, bathers, from passing vessels and storm discharges.

The discharge of a heated effluent, such as cooling water from a power station, can be a useful indicator of local water movement and can be monitored easily at various depths with shipborne equipment. The distribution of surface water temperature can also be determined from the air using thermal imagery. The change in dimensions of the thermal plume would however be dependent on the difference between discharge and ambient temperatures, as well as the physical mixing and movement in the water and therefore may not be immediately suitable for use in modelling unheated effluent.

11.3.3 Dye tracing. The use of a colouring agent to label the seawater would appear to approach the ideal requirement for an indicator of water movement and in practice the technique has many advantages. In the simplest case, dye can be used as a visual indicator of the surface water movement in a similar way to surface floats, without the disadvantages of windage. Simple colouring agents such as vegetable dyes, inks or even emulsion paint can be released in the sea and tracked by recording the position of the mid-point or the perimeter at frequent intervals. Visual dye tracking can be carried out on a number of patches at any one time. This method does not give any indication of vertical mixing and can only be used whilst the patch can be seen and this would vary considerably with atmospheric and sea state conditions as well as the rate of dispersion. Aerial photographs can be of great assistance both in locating the axis of maximum dye concentration and as a permanent record of the visible extent of the dye.

More information can be obtained from dye tracing if the dye concentration can be quantified. A colorimeter can be used to measure the depth of colour in water flowing through the instrument on board a survey vessel, thus giving a continuous picture of the dilution of the dye. However, if a fluorescent dye or tracer is used, then a fluorimeter, which is more efficient in this application, can provide greater accuracy at low concentrations than direct colour measurement.

The fluorimeters used in dye tracing studies generally employ optical filters to reduce the measurement of fluorescence from materials other than the chosen tracer, but if the fluorescence in the water from these materials lies within the filter wavelengths it cannot be removed and is known as the background level. This level is generally in the region of 1 part of fluorescent equivalent in 10^9 to 10^{11} parts of water and varies with the chemical and physical nature of the water and with the wavelengths at which the dye absorbs and emits light. The characteristics of the dye can also limit the upper level of dye concentration measurement by direct flow fluorimetry and accurate determinations can only be made if the sample is first diluted, thus precluding direct flow work.

The fluorescence of various dyes is temperature, salinity or pH dependent and the choice of dye to be used should be made with care. Some dyes such as fluorescein, suffer the disadvantage of being susceptible to photochemical degradation, whilst others such as rhodamine B are readily absorbed by silt particles and some suspended matter. The chemical constituents of dyes should also be considered both for operator hazards and for possible detrimental environmental effects. Results of tests on numerous fluorescent dyes can be found elsewhere [5].

The quantity of dye to be released will be determined by various factors such as upper and lower limits of detectability, expected rate of dilution, itself influenced by currents and sea state, and the desired time scale of the tracing. For example, 2 kg or 3 kg may be sufficient for short coastal experiments on dilution immediately after release, whereas 5 000 kg was used in a central North Sea exercise lasting 23 days. [6].

11.3.4 Radioactive tracers. Procedures for radioactive isotope investigations follow a similar pattern to those for fluorescent tracers in that a controlled release is followed by in situ measurements using sensitive radiation detectors operating directly in the seawater. Readings can be made in the vertical plane rapidly and easily by lowering the detector and either recording a total count for the water column or by halting the detector at various intermediate depths to record radiation levels.

Radioactive isotopes are non-conservative tracers, that is to say the tracer concentration decreases with time, even in the absence of any dilution effect. Measurements made after the release have to be corrected by the decay factor to isolate the decrease in radiation level produced by physical dilution. Safety and practicability together with the study aims dictate the quantity of isotope which can be released. Isotopes with relatively short half-lives have to be chosen if experiments are to be repeated at frequent intervals in one area since accumulation and contamination may otherwise result. A typical water-soluble isotope used for short term dispersion studies is Bromine-82 which has a half-life of 36 h. Other isotopes such as Gold-198 with a half-life of 2.7 days, Phosphorus-32 with a half-life of 14.5 days and Silver-110 with a half-life of 253 days, have been used for longer studies.

Certain special precautions and statutory regulations have to be observed whenever radioactive materials are used and studies involving isotope tracers should be supervised by trained and experienced personnel.

11.3.5 Bacterial tracers. Added bacteria can be usefully employed as sensitive tracers of water movement since single organisms can be recovered from water samples taken after considerable dilution. The sensitivity of the technique can be increased in the laboratory examination by the use of membrane filtration, which allows relatively large sample volumes to be examined.

Pure cultures of tracer bacteria are used to model the behaviour of naturally occurring organisms and in this context they have been used successfully in studies of the discharge or proposed discharge of domestic sewage. The intestinal organism *Escherichia coli* is often taken as an indicator of sewage pollution and the possible presence of harmful organisms (pathogens) such as *Salmonella* species. *E. coli* have a rapid mortality rate in seawater and this, together with the usually strong mixture experienced around the British coasts, explains in part why the British Isles are not surrounded by a sea of sewage. The mortality rate is usually expressed by the time which elapses for 90 % of the original bacteria to die and is called the t_{90} value. This time is dependent on many local factors including the length of time the organisms have been in the sea but it appears that the intensity and quantity of solar radiation are of major importance. Measured values of t_{90} in reasonably clear water typically lie in the range 1.5 h to 9.0 h and a t_{90} of 4 h is often quoted as a generalization for daylight hours. In turbid waters a value of 40 h may be more appropriate.

As noted in 11.3.2, *E. coli* cannot be used as a specific identifier in existing sewage discharges as it would be impossible to identify the source of those recovered. A harmless, easily identifiable organism which is not indigenous to the area is therefore desired, preferably with mortality characteristics similar to those of *E. coli*. The organisms *Serratia indica* and *Serratia marcescens* with t_{90} of the order of 50 % to 100 % greater than that of *E. coli* have been used as such tracers. *Serratia* are pigmented saprophytic organisms producing bright red colonies which can be readily enumerated. *Serratia* can be cultured either for batch release or on a longer-term basis for continuous discharge and the number of organisms which can be prepared for release is typically of the order 10^{12} per litre. Spores of a variety of *Bacillus subtilis* have been used for longer term experiments in conjunction with the radioactive isotope Bromine-82. However, it was noted that the spores could be detected in lower concentrations than could the bromine because of the greater sensitivity of the bacterial method.

Successful studies of water movement have also been made with bacteriophage, viruses which infect bacteria. Any particular bacteriophage will act only on one type of bacterium or closely related species and this parasitic behaviour forms the basis of the laboratory examination of samples. For example, a bacteriophage specific to *Aerobacter aerogenes*, with a t_{90} of around 15 days, has been successfully used in estuarine waters to study the mixing of two river systems in order to locate a suitable site for a sewage effluent discharge [7].

The main disadvantages of bacterial tracers are on the practical side of the survey. Because it is necessary to collect discrete water samples, unless a secondary tracer is employed simultaneously there is no definite indication as to whether the samples will contain any bacterial tracer. Considerable care has to be taken to avoid contamination of the samples both during collection, handling and testing, and a suitable laboratory is essential together with personnel trained in microbiology. There is always a substantial interval between the time when the sample is taken and when the results are available and this compares unfavourably with the rapid dye and radioactivity tracing. For example, the results of tests for *E. coli* would not be available for 18 h and those for *S. indica* not for approximately 44 h. Despite the delay in obtaining results, the advantages of modelling bacteria with a similarly behaving tracer are obvious.

11.4 Presentation and analysis of field data.

The effort and cost of data collection can be significant. It is important that the method of interpretation is considered during the design of the field work, to avoid spending time and money on data which are irrelevant or unnecessary. In particular, the method of position fixing (see 6.3) and its accuracy relative to the requirements of the tracing method should be considered. Interpretation of the data can range from visual intuitive examination of a few results to sophisticated computation of a large quantity of information. It is important to remember the aims and ultimate objectives of the study both when considering the method of data presentation and during interpretation.

Charts play a major role in the presentation of water movement information irrespective of which method of tracing is adopted. At the simplest level, the chart will show only the position of measurement. A pictorial representation of the measured data can be a useful addition, such as a scatter or central vector diagram for current observations or a record of tracer concentration. Charts are obviously essential for presenting data such as float tracks or for showing vessel tracks during dye traverses. Several spot readings can be contoured to show similarities and trends and this can be a useful technique for the discussion of radiation levels or bacterial counts. A summary chart showing water movement in broad terms as derived by the survey can be a useful aid to understanding the current regime of the area. Additional information on other variable environmental conditions such as sea state, wind and tidal levels should be readily available for reference.

12 Waves

Exposure to wave attack can have a profound influence on the selection of sites for maritime structures and the consideration of designs and construction methods requires detailed knowledge and understanding of the wave activity and persistence, in average as well as extreme conditions.

Detailed consideration of wave form, generation, recording, analysis and prediction is included in section 4.

13 Water quality

13.1 General. The interaction between water quality and maritime structures can be considered from two opposite view points. The effect of water quality on the safe and efficient functioning of the structure should be evaluated and this would require the gathering of the usual data on temperature, corrosive elements, suspended solids, marine growth, etc., but the influence of the structure on the water quality and other features of the surrounding environment should also be considered. This is particularly important when deciding on construction methods, material sources and operational details. In addition, the water around a coastal structure may be of considerable economic importance and the effects of construction on fish or shellfish stocks, potential freshwater or mineral extraction and recreation activities should be considered.

13.2 Temperature

13.2.1 General. In coastal regions there is generally a well defined seasonal temperature variation, although throughout the year the water column tends to be isothermal due to strong turbulent mixing. Significant stratification may exist, however, in areas where there is a thermal effluent or in estuaries with high freshwater discharge.

Temperature variation has effects as follows:

- a) *Ice formation.* Sea icing may become a problem when the water temperatures fall below -2°C . However, floating ice masses formed elsewhere can survive when the water is considerably warmer. When considering icing on a structure, wind strength and air temperature are of prime importance; however icing is unlikely to occur until minimum sea surface temperatures fall below 6°C .
- b) *Corrosion.* Higher temperatures will increase the rate of iron oxide formation and may have a significant effect on bacterial corrosion.
- c) *Marine growth.* The rate of encrustation on a structure and the species of organism present will depend on the temperature of the environment, higher temperatures promoting more vigorous growth.
- d) *Effluent dispersion.* The density of sea water is a function of its temperature and salinity and is a fundamental parameter to be considered when modelling the behaviour of an effluent immediately after release.

13.2.2 Measurement. Different applications require different methods of measurement. Surface temperature variations over a large area can be determined using infrared techniques from either an aircraft or satellite. Variation at a point can be monitored by comparison of multiple passes of the remote sensing apparatus. On a smaller scale or where depth profiles are required, continuous or repetitive measurements are taken using thermal sensors such as thermistors, resistance bulbs, thermocouples and mercury-in-glass thermometers.

13.3 Chemistry. The chemistry of the water should be determined at an early stage of the site investigations, with particular attention being paid to potentially corrosive elements such as chloride and sulphate ions (see also 49.12). Coastal water is generally fully saturated with oxygen at the surface but if there is little vertical mixing the oxygen content will decrease with depth. Under normal circumstances this decrease is unlikely to have a significant effect until anaerobic conditions are reached but the local distribution and seasonal variation should be considered when siting outfalls to discharge effluents which could act as reducing agents.

The important chemical parameters are usually analysed directly or measured with selective ion electrodes, either in the field or from specific collected and stored samples in the laboratory.

13.4 Turbidity. Turbidity is generally caused by suspended clay or silt particles, dispersed organics and micro-organisms. A lower water temperature will increase the amount of sediment that can be transported in suspension due to the viscosity change.

Turbidity should be considered in harbour design, with special reference to sediment movement and siltation studies and when abstracting water for commercial purposes, particularly with regard to wear on pumps and blockages.

The most rapid changes in turbidity generally occur during dredging operations and the consequences should be borne in mind during the planning of the initial site preparation and maintenance dredging. Mixtures of fine sand and muds with organic matter tend to support a greater variety and number of benthic, i.e. bottom-living, organisms than coarse, clean, unstable sand, gravels or soft muds and so dredging in muddy sand will have a greater ecological impact. Detailed consideration should also be given to the area of spoil disposal, not only for the economic disadvantage of dispersion with possible redeposition back in the dredged area but also for the likelihood of deleterious effects to the resident flora and fauna.

13.5 Marine life

13.5.1 Effects of marine life on structures. Many forms of marine organisms including algae, molluscs, crustacea and others will attach themselves to a maritime structure. The organisms can cause blockage of intake and discharge pipes, impose or increase mechanical stresses (see 47.2.2), accelerate degradation, retard flow or simply impede inspections for maintenance or certification purposes [8]. Methods of controlling marine growth include the use of antifouling paints and mechanical removal by hand scraping or water or air jetting. As well as surface-attaching species, structures with timber elements may be affected by boring organisms (see 60.2). The presence of molluscs on the surface of a steel structure can inhibit corrosion and their removal is not always beneficial (see 68.1).

13.5.2 Effects of structures on marine life. Shore-connected construction may result in long term changes in the maritime environment, but in nearly all cases the significant pollution aspects of these structures are of short duration, limited to the construction and installation activities. The more serious potential for pollution associated with these structures generally arises from their use and operation rather than from their presence in the maritime environment [9].

If a major development project is planned, then an environmental impact assessment may eventually be necessary which should include the environmental, social and economic effects of the proposed development. Methods for evaluating these effects in an impact assessment are still fairly rudimentary and most make use of value judgements. For details of these methods specialist texts should be consulted [10, 11].

13.6 Pollution

13.6.1 General. If it is likely that there will be a discharge of potential pollutants from a maritime structure, either during normal operation or due to accidents, a baseline survey should be carried out to define conditions before discharge and a monitoring programme established to identify changes in the environment during discharge. Baseline surveys generally include data on the physical environment and analyses to determine existing levels of particular chemicals in sediments, water, air and marine organisms. The monitoring programme may repeat the same analyses at regular intervals, or following particular occurrences likely to cause changes, such as accidental spillages.

13.6.2 Examples of discharges

13.6.2.1 Oil. Operational spillages can be minimized by taking adequate precautions, in particular the training of competent operators. In the case of accidental spillages, the authority responsible should maintain adequate stocks of cleansing equipment and have detailed knowledge of water movement in the local area so that personnel and supplies can be efficiently deployed.

13.6.2.2 Trade effluent. The discharges and their effects on the environment should be monitored and pollution kept to an acceptable level.

13.6.2.3 Domestic effluent. The pollution from sewage is predominantly bacteriological and visual. Pre-construction surveys should be carried out to study stratification, water movement and bacterial mortality and hence to decide on a suitable outfall location.

13.6.2.4 Heated water discharge. The effect of the increased temperature on marine life can be considerable, increasing the metabolic rate and decreasing the species diversity.

14 Sediment transport

14.1 General. In any operation involving the alteration of the inshore hydrodynamic regime, the subsequent effects on sediment movement have to be considered. It is in the inshore zone that energy generated at sea is transmitted to the land in the form of waves, tidal currents, etc. and it is the sediments, rocks and man-made structures of the area that are responsible for attenuating this energy. The sediment of the littoral and sublittoral zones is moulded into a topography and as long as the balance of forces is maintained, the system will be in dynamic equilibrium. If one of the system components is altered the remainder of the system will have to adjust in order to achieve a new dynamic equilibrium. Such is the delicate balance of nature that what may appear to be a minor alteration can bring about large scale changes to the system as a whole often with expensive and dangerous consequences.

The natural parameters that define the rate and direction of sediment transport are the prevailing currents, both tide and wind generated, waves, bathymetry and the properties of the seabed or beach sediment. Currents and waves are the agents responsible for entraining, transporting and depositing sediment. Bathymetry imposes constraints on currents and waves and hence on erosion and deposition. The size distribution of the indigenous sediment generally reflects the competence of the transporting agents, subject to the availability of material.

A general appreciation of sediment transport in an area can be gained by studying old charts and photographs, including aerial views, and in the case of beaches, by carrying out a preliminary inspection. Historic information can then be compared with modern details and changes of depth and apparent movement of features such as offshore sand bars can be studied to indicate the transport of sediment. In a preliminary beach inspection, features such as spits and accretion or scour against existing structures will be indicative of the direction of the drift and intensity of sediment transport.

14.2 Sediment transport in currents

14.2.1 General. When a current flows over a bed of erodible sediment a certain minimum or threshold bed shear or current is required to initiate movement. For flat beds composed of fine or medium sand (grain diameter 0.1 mm to 0.6 mm) the threshold current appears to be about 0.15 m/s measured at 0.3 m above the bed, although that required to move silts (size < 0.06 mm) and gravels (size > 1.0 mm) has been found to be greater.

When the current exceeds the threshold value, the bed begins to erode, the displaced particles being carried over the bottom by sliding, rolling or saltation, i.e. bed transport, or by being lifted into the body of the water by turbulence, i.e. suspended transport. For fine-grained sediments, both modes are usually present at the same time and it is difficult to distinguish the boundary and the level at which suspended transport is initiated. It is generally considered that suspension becomes appreciable when $v_s/v_* \approx 1$ where v_s is the average fall velocity of the particles in still water and the friction velocity $v_* = \sqrt{(\tau_0/\rho)}$ where τ_0 is the shear stress exerted by the water on the bed and ρ is the water density.

Generally beds subject to erosion form small scale ripples and larger scale dunes which, while displaying a certain average wave length and height, vary in size, have flat upstream slopes and steep downstream slopes, are usually short crested and migrate slowly in the direction of the current.

14.2.2 Measuring suspended sediment load

14.2.2.1 General. Most satisfactory results are achieved if sediment transport is regarded in terms of sediment flux. This is usually measured directly in the field at several stations at frequent intervals, usually half-hourly, on both neap and spring tides. The flux is obtained by the integration of the product of the water velocity and the concentration of suspended solids over the depth.

Devices for measuring suspended load are described in 14.2.2.2 to 14.2.2.4. For the samplers described in 14.2.2.2 and 14.2.2.3, the grain size distribution is determined by standard sieving, settling column or Coulter counter techniques and the subsequent numerical integration can then be performed.

14.2.2.2 Depth integrating sampler. This collects and accumulates a sample as it is lowered to the seabed and lifted back again. The sampler should be moved at a uniform rate in a given direction, but not necessarily at equal rates in both directions. This equipment is restricted in use to shallow depths by its capacity to store the water sample.

14.2.2.3 Point integrating sampler. This operates in almost the same manner, except that it has an inlet valve which can be opened or closed as required. Thus, it is possible in deep water, to point sample at known depth intervals and then integrate over the entire depth.

14.2.2.4 Light extinction meter. This is commonly, but incorrectly, called a siltmeter. It incorporates a light source and a photocell and variations of suspended solids concentration cause fluctuation in the amount of light reaching the photocell, which is connected to a meter. A calibration curve should be established so that meter readings can be converted to concentrations of solids for the particular material in suspension. Since it is not usually practical, because of the bed features, to measure closer than about 0.3 m above the seabed, where the concentration is high, an extrapolation to lower heights above the bed is often made, based on theoretical arguments.

14.2.3 Measuring bed transport. For fine sand and silt, bed transport is usually small in comparison with suspended transport, but may become relatively appreciable with increasing grain size. There are primarily two methods for studying the movement of bed load; those which use laboratory-derived bed load formulae (see 14.2.4) and those which rely on field measurements (see 14.2.5). Direction and rate of bed transport can be estimated by employing fluorescent and radioactive tracers and the bed load can be sampled by using sediment traps or specialized equipment such as the Arnhem or Dutch pressure difference bed load samplers. The practical difficulties of using these traps and samplers in the field and consideration of their efficiency has reduced their popularity, with a corresponding increase in the use of bed load formulae.

14.2.4 Bed load formulae. The main types of bed load formulae consider transport rates from relationships of shear stresses, flow and statistical considerations of lift forces. All equations rely to some extent on experimental data from flume studies to determine their various integral coefficients. For details of these equations and their applications, reference should be made to specialist texts [13].

14.2.5 Field tracer studies

14.2.5.1 General. These generally make use of coloured tracers, radioactive tracers or, occasionally, heavy mineral tracers. Radioactive tracing has a notable advantage over the use of coloured materials as measurements can be made rapidly in situ without the need to retrieve a sample or count the grains. However, some vertical cores should be taken whichever technique is used, to determine the depth of movement of bed material and hence quantify the total bed transport. Cores may also clarify the confusion which can be generated by the ability of the radioactive technique to detect buried, labelled particles and the resulting uncertainty as to whether a low level of radiation is due to a low source on the surface or a higher level from a buried source.

Problems of depositing the labelled material are common to both techniques as in theory it should be fully integrated with the bed throughout the movable depth. An initial tidal bias can also be introduced depending on the time of release, although this can in part be overcome by injecting half the tracer at high water slack and the other half at low water slack. These problems can both be minimized by allowing time for the labelled sediment to mix thoroughly with the seabed and by ignoring the first few days' results.

All tracing experiments indicate only the movement that has occurred during the period of the experiment. For radioactive tracers that have a relatively short half-life this may only be a period of a few weeks and coloured sand may also be dispersed after a short time. Unless weather and wave conditions are similar to those of the long term average, non-typical results may be produced. Generally the direction of sediment movement is much easier to determine than its magnitude which may be considerably in error, depending on circumstances. It should be noted that the techniques described can also be employed to study suspended sediment transport of non-cohesive grains. Considerations of flocculation and aggregated size confuse and hence generally restrict the use of radioactive tracers for silt and clay sizes.

14.2.5.2 Coloured tracers. Coloured tracers involve the coating of non-cohesive sediments with either a distinguishing coloured paint or a fluorescent substance. Indigenous sediment may be used for this purpose, but where it is not practicable to treat a large quantity of local sand, material of a similar density and size distribution may be substituted, provided that it will respond to the hydraulic processes in exactly the same way as the indigenous sediment.

The quantity of labelled material to be used will depend on the proposed duration of the test and the expected strength of the waves and currents but generally it has been found, in the case of long-shore drift investigations, that 50 kg to 100 kg per week of study is an appropriate amount.

The sampling routine depends on the environment being studied. Samples should be taken at a maximum spacing of 30 m on each side of the injection point and the basic requirement is that a surface sample of uniform area is retrieved. The method of achieving this will depend on the grain size. For instance, with sand-size material, a simple method is to press a grease-coated card into the sediment. In the laboratory, the grains are counted by eye either in natural light or, in the case of the fluorescent grains, under an ultra-violet light, to yield the concentration of tagged grains. The distribution of labelled sediment can then be plotted on a chart and contoured to show the displacement from the injection point.

14.2.5.3 Radioactive tracers. The usual radioactive tracer technique involves the preparation and irradiation of artificial sediment which has hydraulic properties similar to those of the bed sediment and which is then used to label the local material. Isotopes such as Barium-140, Lanthanum-140 or Scandium-46 are often employed. Care has to be taken when choosing an isotope to ensure that it will have no harmful effects on the environment and to match the half-life of the isotope to the duration of the experiment and the levels at which the isotope can be detected. It is generally not practical to label large particles in the same manner, as the acceptable levels of radiation for release would correspond to relatively few individual grains with reduced likelihood of relocation. The Hydraulics Research Station, Wallingford, Berkshire, however, has recently developed a method of labelling shingle which involves the sealing of the isotope, in the form of a short length of activated silver wire, into a hole in the pebble. With the development of a wide-sweep detector, it has proved possible to relocate a significant proportion of the pebbles and a typical quantity of 1 000 pebbles has proved adequate.

The labelled sediment can then be traced with a sensitive radiation detector and sediment movement can be described by plotting and contouring radiation levels.

14.2.5.4 Heavy minerals. Heavy minerals represent the accessory and varietal minerals of igneous and metamorphic rocks and are operationally defined as those minerals which have a specific gravity greater than 2.85. They probably account for no more than 0.1 % to 0.5 % of terrigenous sedimentary rocks and providing there is a source rock relatively near to the study area, their distribution and relative quantities can be useful in indicating the general direction of sediment movement. If sediment cores are taken, the vertical distribution of the heavy minerals can also be determined and this could yield much useful information on past sediment movement. Heavy mineral analysis can be expensive and great care has to be exercised in the selection of indicator minerals with due regard being taken of the complexity and potentially long time scale of geological processes.

14.3 Sediment transport with waves

14.3.1 Movement due to wave-generated currents. Waves alone can initiate movement of sediment when the maximum orbit velocity they induce near the bed exceeds about 0.15 m/s, as for currents alone. For fine sand, the particles rock backwards and forwards and form ripples with crests parallel to the wave crests. These are typically more symmetrical and periodic than those formed under steady currents (see 14.2.1). As the orbit velocity increases, the ripples become steeper and the sand is taken into suspension by eddies shed from the crests. In the presence of tidally induced currents, it appears that the oscillatory motions caused by waves act as an additional stirring agent at the bed and the concentration of suspended sediment is increased [14, 15].

Large eddy effects can be caused by wave-induced currents associated with diffraction at the sheltered side of the breakwaters (see 29.2.4) and they are thought to be capable of redistributing sediment within harbours.

14.3.2 Littoral drift. In the longshore direction, currents can be induced by the tangential momentum of waves breaking at an angle to the shoreline. Such currents are restricted mainly to the area inshore of the breaker zone. Typically their strengths are low which suggests low transport rates. However, the breaking waves create considerable bottom turbulence which lifts material up into the longshore current where it can be transported some distance, resulting in a high net sediment movement. Several empirical formulae have been proposed relating longshore drift of sediment to the breaker height and specialist texts should be consulted [16]. Littoral drift can also be measured using the tracer techniques discussed in 14.2.5.

Littoral drift can be an important agent in the shaping of the local coastline and requires careful study whenever construction is contemplated which may disturb the dynamic equilibrium of the local drift regime (see 14.1 and 14.4 to 14.6).

14.3.3 Rip currents. Generally there appears to be little convection of water between the offshore area and the breaker or surf zone, but along some shorelines rip currents, consisting of concentrated jets that carry water seaward through the breaker zone, can occur. It is thought that these may be caused by the interaction of wave set-up and edge waves (see 24.3). Rip currents with speeds exceeding 1.0 m/s have been reported and it is noteworthy that they are the only currents easily capable of transporting sediment seawards. At present it is not possible to predict the strength or spacing of rip currents and there is insufficient information to indicate quantitatively how important they are as sediment transporting agents in the context of net movement.

14.4 Accretion and scour

14.4.1 General. Whilst the above techniques give an estimate of the rate and direction of sediment transport in an area, in many engineering problems it is desirable to produce a direct estimate of the amount of accretion or scour. Such a situation frequently arises in the planning of navigation channels. It should be noted that predictions of this type are uncertain and an estimate which is within 25 % of the final quantity may be considered as good.

14.4.2 Trial trench method. The most obvious method of estimating accretion or scour rates is by trial dredge. A series of trial holes are dug on the line of the proposed channel and the rate of infill determined from successive bathymetric surveys. Such trial holes should be approximately rectangular in plan and orientated with the length parallel to the channel. Ideally the hole should be dug to the same depth and breadth as the proposed channel and the length sufficient to avoid end effects, i.e. accretion at the ends which is not typical of the channel as a whole. Usually a length to breadth ratio of about 10 is sufficient, the infill rate being determined from surveys taken near the mid-section of the trench.

14.4.3 Accretion/scour plugs. This method is suitable for use in the intertidal zone at each site of interest but can be used in the nearshore zone if divers are employed. The technique involves the removal of several cores of sediment and replacement by an artificial distinguishable material with similar erosion properties. The amount of accretion or scour can then be estimated by recovering the core and surrounding sediment and measuring directly the amount of sediment deposited or eroded.

14.5 Bed-form migration. The direction of sediment transport and a qualitative appreciation of the rate of transport can also be gained by observing the migration of current-produced bed forms. Bed-form migration appears to be controlled by the time-velocity asymmetry of bottom tide-generated currents and the sediment grain size. The method of study will depend on the required resolution. The most accurate measurements can be made using photogrammetric methods which, under favourable conditions, can be resolved to a scale of millimetres with complete areal cover. Precise levelling by divers, coupled with a tracer experiment, can give point measurements accurate to a scale of centimetres but this technique gives lower overall accuracies dependent on the line spacing. Conventional time-lapse underwater photography can also offer reasonable point or line accuracies under good visibility. Remote techniques such as echo-sounding and side-scan sonar surveys offer less resolution but, bearing in mind the qualitative nature of the results, are probably more practicable. These techniques can produce good results with the larger bed features such as sand waves.

14.6 Models. For certain operations, such as in the construction of breakwaters or causeways, it may be desirable to design a physical or mathematical model of the system in order to predict any changes to the sediment transport paths for various proposed schemes. With a physical model, the objective is to produce an accurately scaled model of the prototype. This is achieved by undertaking field observations and measurements which can be related to the model by a dimensional study of the prototype characteristics. The model is proved when it accurately reproduces known past and existing conditions. It can then be used to predict changes in the system brought about by future alterations to the environment.

A mathematical model operates by defining the processes and responses of the system in terms of mathematical relationships and, by necessity of the complexity of the model, is run on a computer. Validity is tested, as with the physical model, and prediction is performed by adjusting the relevant variables such as boundary conditions, wave height and current strength.

Both types of model have virtues and inherent limitations. The biggest disadvantage of the physical model concerns distortion resulting from the inability to scale certain system characteristics. For example, it is difficult to scale sediment movement since, if the sediment size is scaled, the viscous forces on the grains become relatively too large and the grains become so small that cohesive forces predominate. On the other hand a mathematical model may be an over-simplification or even misinterpretation of reality. Knowledge of the mechanisms of sediment transport and hence the governing equations is as yet incomplete; thus a mathematical model of sediment transport has to be an approximation. The best solution to the problems of modelling is probably a combination of the two techniques.

The accuracy of model predictions, whether mathematical, physical or a combination of both, varies widely, depending on both the complexity of the site situation, and the accuracy and quality of field data used in setting up and determining the validity of the models. Models are often indispensable for determining which of several proposals is the most suitable for site application as they can give a guide to the probable long term changes in the bathymetry. They are less able to determine how quickly such changes will take place and hence the rates of accretion or scour.

Section 3. Operational considerations

15 General

This section gives guidance on the general aspects of design life of structures, ship data, navigation in approach channels, ship handling in harbours and other operational considerations.

Many of the operational requirements of a maritime structure are specific to the particular function or functions of the individual structure and guidance on these aspects will be found in subsequent Parts of this code. However, in all projects, close liaison should be maintained with the client or operator so that the maximum operational benefits can be obtained in terms of safe and economic functioning of the finished installation. The following subjects should be considered for possible individual study in each case:

- a) numbers, types, sizes and shapes of present and/or expected vessels;
- b) provision of tugs, navigational aids and marine traffic control;
- c) pilotage;
- d) berthing and mooring patterns, practices, systems and load measurements;
- e) requirements of cargo handling, roll-on roll-off (ro-ro) traffic, storage and other activities, including the need or otherwise to allow for future change, or flexibility in operational usage;
- f) regulations affecting any of the above operations.

16 Design life of structures

The design life of a structure is taken to be its intended useful life and will depend on the purpose for which it is required. The choice of the design life is a matter to be decided in relation to each project since changes in circumstances and operational practices can make the structure redundant or in need of substantial reconstruction before the end of its physical life. However, the following values may be regarded as minimum requirements:

- a) quay walls: 60 years;
- b) open jetties: 45 years;
- c) superstructure works: 30 years;
- d) dry docks: 45 years;
- e) shore protection works and breakwaters: 60 years;
- f) flood protection works: 100 years.

It should be noted that the design life will not necessarily be the same as the return period of the design condition since such an equality implies a 63 % chance of the design condition occurring during the design life (see 21.4). This may not be operationally acceptable for some structures, particularly major protection works.

The design life is significant when assessing:

- 1) time-dependent factors running against the security of the structure such as fatigue loading, corrosion, marine growth and soil strength reductions;
- 2) probability levels for limit state design and for design condition return periods;
- 3) economic feasibility of the project and future developments.

In view of the variable and often unpredictable character of the forces to which maritime structures are subjected, it is frequently unrealistic to expect substantial cost savings to result from attempting to design them for short lives. Generally, greater overall economy will be achieved by choosing simple robust concepts and appropriate reliable construction procedures.

17 Ship data

17.1 General. Where possible, details and dimensions should be obtained from the relevant authorities, owners and operators for the actual vessels to be accommodated and those likely in the anticipated lifetime of the structure.

Vessel characteristics which should be considered include type, size and shape, ship handling requirements, cargo or passenger handling requirements and vessel servicing requirements.

Characteristic dimensions of passenger vessels, naval vessels and vessels of less than 20 000 t displacement vary considerably according to function, age and operational region. Approximate dimensions of the larger bulk carriers and container ships are given in 17.3. These values are approximations and should only be used for preliminary planning purposes. General guidance on vessel dimensions may also be obtained from the registration particulars [17].

Ship handling considerations are discussed in clauses 18 and 19. Guidance on cargo handling and servicing requirements is to be found in subsequent Parts of this code.

17.2 Tonnage and displacement. While naval vessels are customarily described by displacement tonnage, the size of other vessels is frequently quoted in terms of gross registered tonnage and deadweight tonnage. The latter values are significant for registration and in assessing the carrying capacity of the vessel. However, for computing berthing energies (see clause 41) and other hydrodynamic calculations the displacement of the vessel is required.

For the purposes of preliminary planning the following relationships may be used to obtain displacement from gross registered tonnage or deadweight tonnage. These values are approximations and should not be used for detailed design unless confirmed by the actual vessel characteristics.

- a) Fishing boats:
 - small: $\text{grt} \times (2.5 \text{ to } 2.0)$;
 - large: $\text{grt} \times (2.0 \text{ to } 1.5)$.
- b) General cargo:
 - $\text{grt} \times 2.0$; or
 - $\text{dwt} \times (1.6 \text{ to } 1.4)$.
- c) Passenger liners: $\text{grt} \times 1.1$.
- d) Container ships: $\text{dwt} \times 1.4$.
- e) Bulk carriers: $\text{dwt} \times (1.3 \text{ to } 1.2)$.

Where two values are quoted in the above relationships, the first approximates to the smaller vessels of a given type.

17.3 Typical container ship and bulk carrier dimensions. For the purposes of preliminary planning, Figure 1(a) and Figure 1(b) may be used to obtain typical values of container ship and bulk carrier dimensions respectively. These values are approximations and should not be used for detailed design unless confirmed by actual vessel characteristics.

18 Navigation in approach channels

18.1 General. From the operational view point ideal accessibility to a harbour implies:

- a) a straight, wide approach channel, the direction of which coincides with the direction of currents and of the highest waves;
- b) a wide harbour entrance;
- c) a large area within the harbour for turning and manoeuvring to jetties and quays.

Such an ideal layout can seldom be achieved, particularly for harbours on the open coast, because the dominant currents rarely coincide with the direction of the highest seas. Ports located in estuaries, where the hydraulic conditions are determined mainly by the tides, generally offer better protection for seagoing navigation and many of the larger sea ports are situated in such locations. Access problems may still arise, however, since vessels may be required to follow the sinuous course of a natural channel and finally cross the tidal currents to the harbour entrance or riverside quays. Often extensive dredging works have to be carried out to meet the increasing navigational demands of larger vessels and considerable maintenance dredging costs may be incurred to remove siltation both in the artificially deepened access channel and in the harbour itself. The demand for deeper channels and reduction in dredging costs is tending to bring about the construction of new port facilities for large vessels nearer to deep water at sea.

18.2 Studies. Where access channels are to be aligned or alternative routes found, the opinion of experienced masters and pilots is essential. Such advice can be supplemented by model and/or simulation studies.

In one method, model vessels having similar hydrodynamic behaviour to the full scale vessels are studied in small scale harbour models in which different designs of harbour entrance, breakwaters, quays, jetties and other structures, can be tested. The speed of the model vessel, its rudder settings and any bow and stern thrusters provided to simulate the action of tugs are usually radio controlled and the manoeuvres recorded by overhead photography. This type of experiment is of limited value, partly because the operator has a bird's eye view of the situation and his response is almost immediate and partly because a skilled operator rapidly learns to manoeuvre the vessel safely in a given situation. The experiments can, nevertheless, be useful in developing a strategy for coping with difficult navigational conditions of current, wave and wind.

Another method uses larger manned ship models which may be controlled by one or two operators, one of whom may be an experienced mariner. This method overcomes the problem of the operator's bird's eye view by presenting him with a more realistic view of the situation. The problems of a contracted time-scale are not entirely overcome, however, although the bigger the model, the smaller the problem.

The final and perhaps most comprehensive method of evaluating ship handling in or near a proposed harbour or waterway is by means of a ship simulator in which vessel behaviour, bridge layout and view from the bridge are all realistically reproduced. The central feature of these simulators is a computer which is programmed for the seabed profile and different ship types, with the aid of information obtained from full-scale observations and from model tests carried out in basins in which waves and currents can be reproduced. The simulator enables typical ships to be manoeuvred along proposed approach channels in real time and therefore overcomes the time-scale problems mentioned above. In addition such a facility allows a realistic assessment to be made of the safety of the waterway from the point of view of navigation.

18.3 Depth of channels. The required depth of channel is largely governed by the underkeel clearance to be allowed for the largest vessels using the port which, for economy of dredging, may be limited to passage only near high water. This sets a minimum transit speed at ports with long approach channels and increases the risk of encounters between such vessels.

The underkeel clearance to be provided should take account of squat. Squat is normally divided into two components, mean sinkage and dynamic trim. As a vessel proceeds along the channel, the displacement of water causes an increase in return currents along the sides of the vessel and between the channel bed and the underside of the vessel. This is offset by a lowering of the adjacent water level, causing the vessel to experience sinkage and change of trim. In addition sufficient clearance should be allowed to take account of the vertical movement of the vessel in heave, pitch and roll produced by waves.

Squat increases with the length of the vessel, with the square of the forward speed and with reduction in underkeel clearance. Formulae have been developed on the basis of theory, model test data and full-scale measurements which allow the squat to be estimated for ships sailing in shallow open water. These formulae have been used to produce the squat estimation chart shown in Figure 2 for vessels with block coefficients between 0.8 and 0.9, i.e. large bulk carriers [18].

Additional squat is experienced by each of two ships when they pass, the effect being accentuated with reduction of underkeel clearance and vessel separation as well as with an increase of speed, and additional sinkage is also caused by sailing in the proximity of a channel bank [19].

The vertical movements under waves and swell depend on the wave height and direction and the ratio of the wavelength to the relevant characteristic dimension of the ship, i.e. length for pitch and heave and beam for roll. These factors determine the forces exciting the motion. The response of the vessel to these forces is mainly governed by the ratios of its natural frequencies in heave, pitch and roll to the encountered wave frequency and by the damping of the motion in these modes.

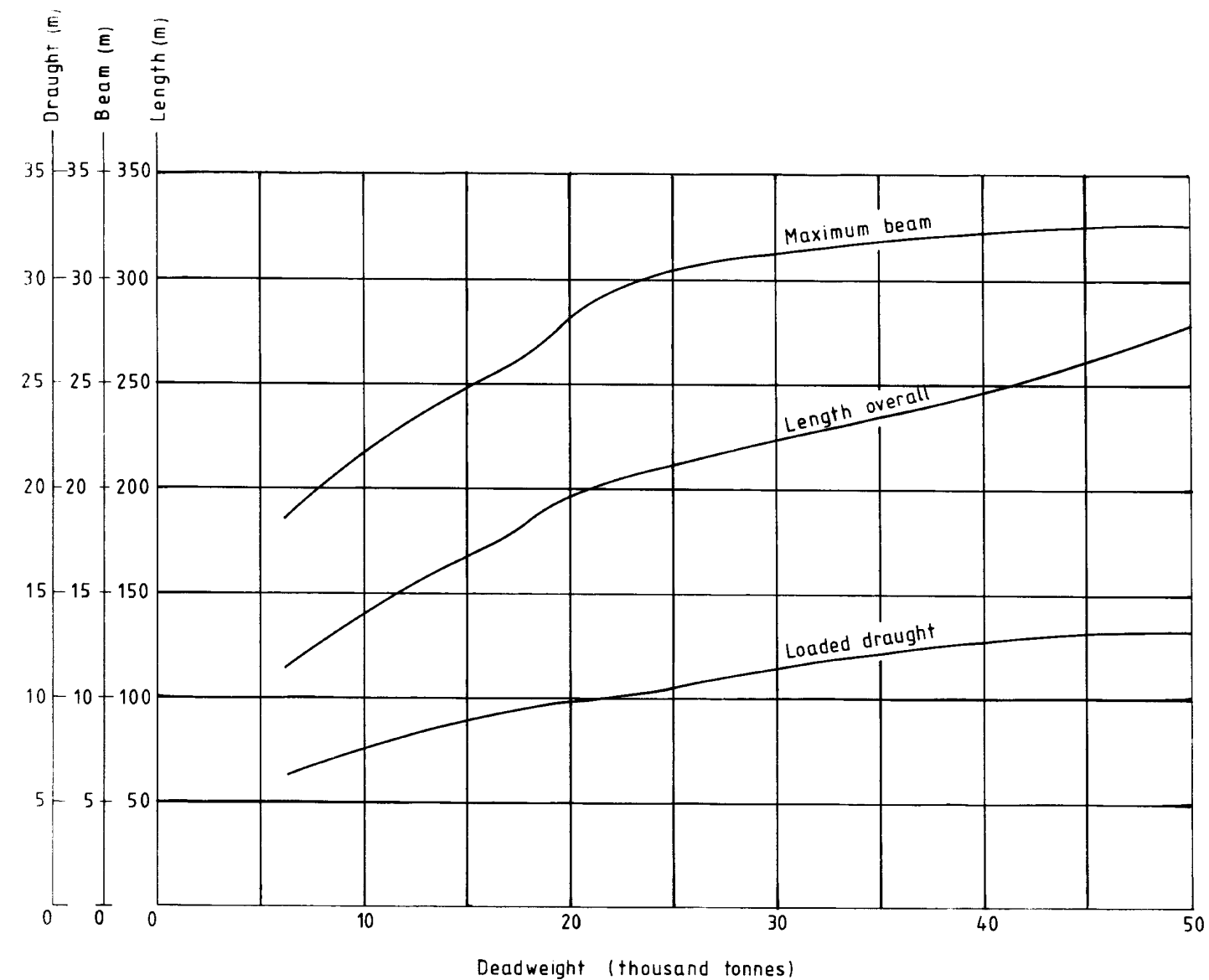
Usually investigations of the vertical movements of ships in waves have been concerned with their sea-keeping qualities in deep water and estimates have been based on model tests and theoretical predictions. A graph illustrating the results of such investigations is shown in Figure 3 [18].

Unfortunately there are practically no full-scale measurements of vertical ship movements in channels where the underkeel clearance is small and few experimental studies have been carried out for such cases. It is known that with small underkeel clearance both the natural period, due to increase in added mass, and the hydraulic damping in each mode of movement, are increased (see 31.2). In view of the lack of information on this subject, it is recommended that model studies should be carried out in specific cases to determine the limiting wave conditions and dredged depths of the access channel, having regard to the largest size and type of vessel to be accepted (see 18.2).

Where the bottom of the channel consists of mud or silt it is usual to define a nautical depth from the water surface to the level at which the density of the bottom sediment is equal to or greater than $1\,200\text{ kg/m}^3$ since research has shown that mud layers of lower density do not significantly impede the passage of a ship. It should be noted that, depending on its operating frequency, an echo sounder will identify as the seabed muds of significantly lower density whereas a sounding lead will sink until supported by muds of greater density than $1\,200\text{ kg/m}^3$.

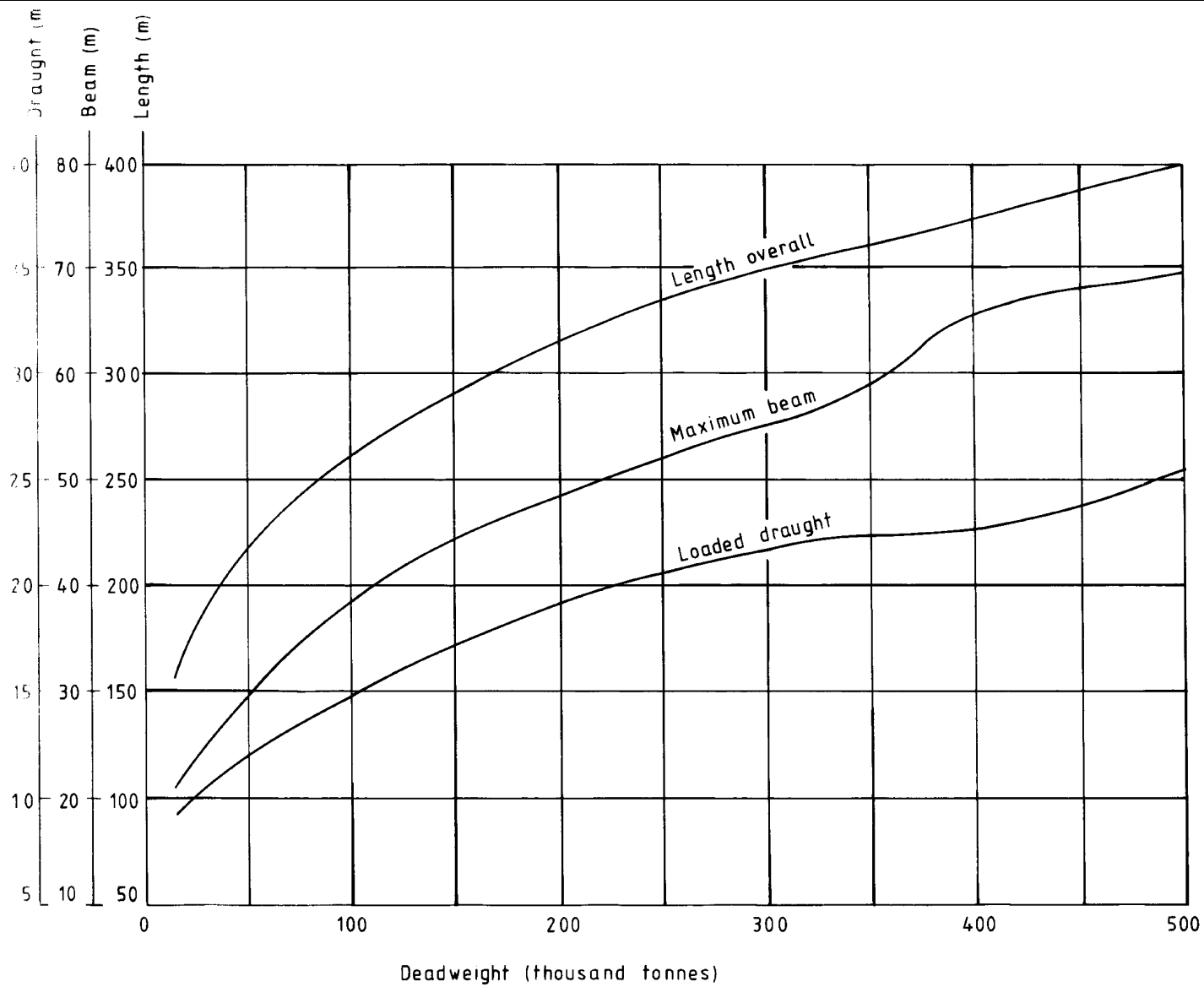
18.4 Width of channels. The width of access channels is governed mainly by the steering characteristics of the vessel in response to the pilot and helmsman, considered as a closed control loop, when subject to external disturbances such as the hydrodynamic effects of bank suction, cross-currents, wind, waves and other traffic. Large vessels generally have relatively long time constants and may be rendered even more sluggish in their response to a given force applied by the rudder, due to the increase in the hydrodynamic forces and added mass of the ship when the underkeel clearance is small. Thus in negotiating channels with bends, large changes of helm and engine speed are common and even in straight restricted channels pilots tend to take a sinuous course. The efficacy of new channel alignments and dimensions, navigational aids and training methods can be studied in ship handling simulators (see 18.2) in which the response of the vessel and pilot to changing conditions can be reproduced in real time and the burden on the skill of the navigator can be assessed.

In a survey of one-way ship traffic in 10 major UK and overseas ports with channel widths of 300 m or less at their narrowest sections, the ratio of the channel width to the beam of the largest vessel accepted was found to lie between 4 and 6 depending on local conditions. The ratio found in this survey is not regarded as an operational criterion in these ports, however, since no port, as far as is known, limits the size of vessel by any formal width standard [18]. For somewhat smaller vessels passing one another, the minimum width of channel appears to be about six to eight times the average beam of vessels depending on the exposure and straightness of the channels. For large tankers, of up to 300 000 dwt, with either straight or curved channels subject to cross-tidal currents, recommended ratios of channel width to beam lie between 5 and 7 [20]. It is strongly recommended that two-way traffic of large tankers should be avoided whenever possible.



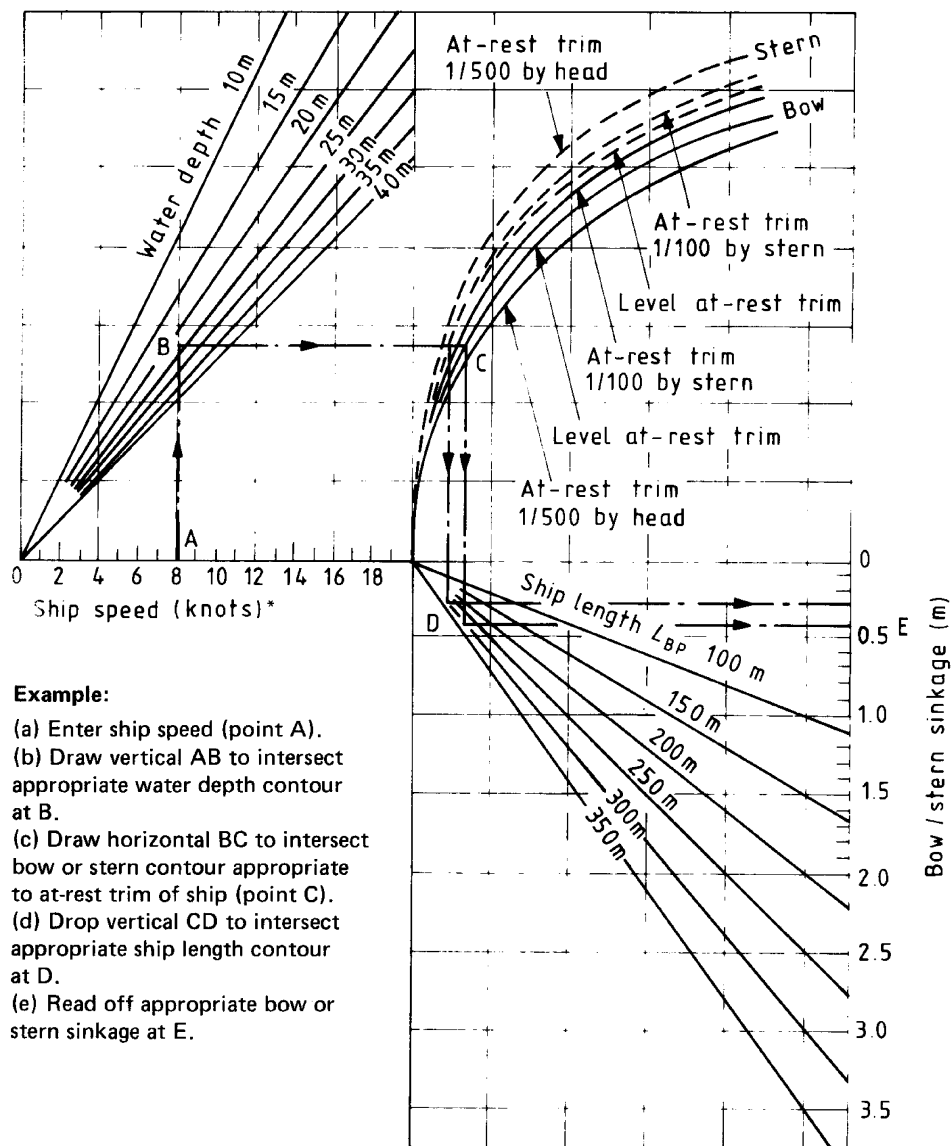
(a) Container ship

Figure 1 — Typical ship dimensions



(b) Bulk carrier

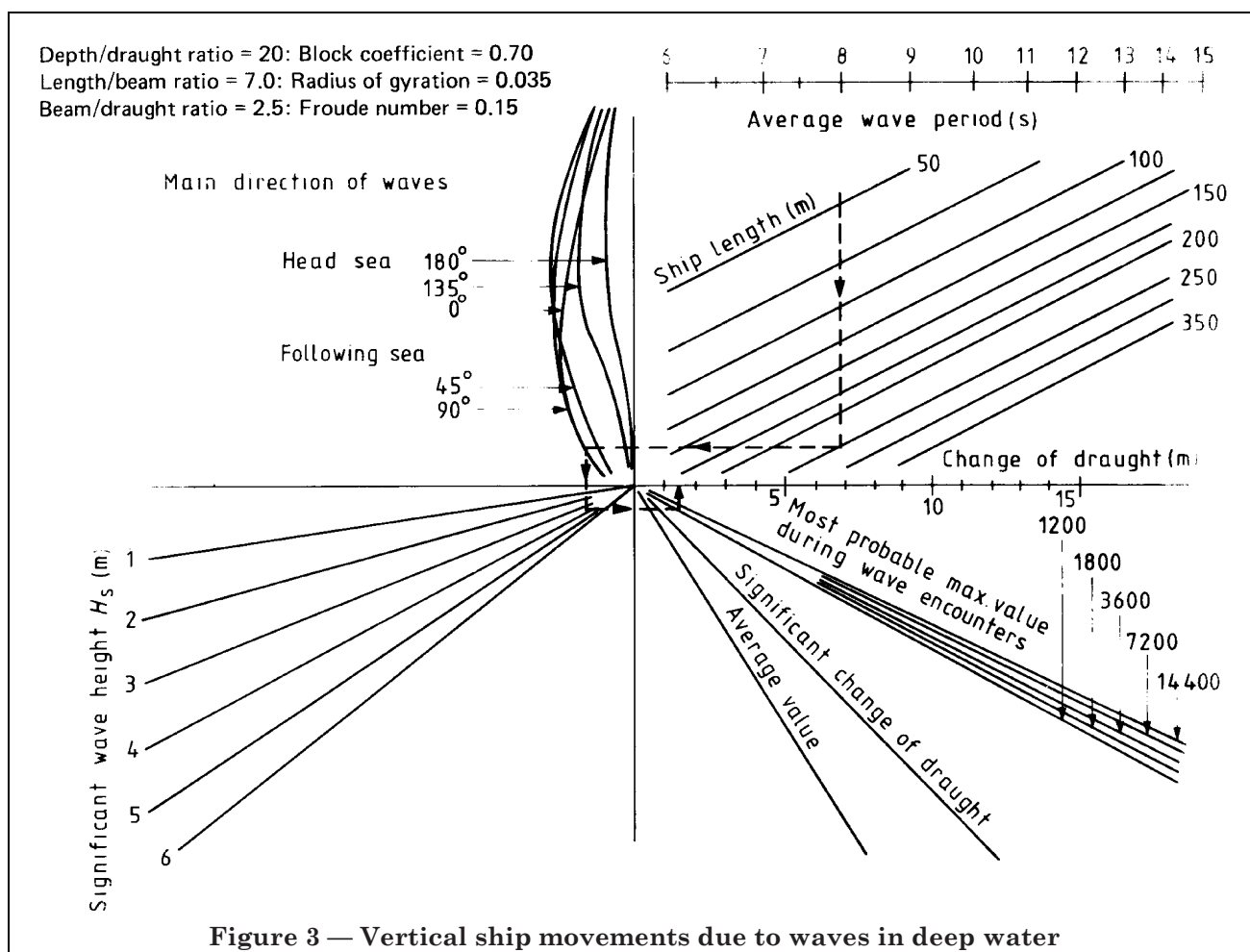
Figure 1 — Typical ship dimensions (concluded)



Applicable to ships with block coefficient C_B from 0.8 to 0.9, length to beam ratio $L/B_v \approx 6.0$, beam to draught ratio $B_v/d_m \approx 2.6$, and water depth to draught ratio d/d_m from 1.1 to 1.5.

* 1 knot $\approx 0.514 \text{ m/s}$.

Figure 2 — Estimates of squat



It can be argued that it is more appropriate to use vessel length to specify the minimum channel width since it is the changes in yaw angle, governed by the rudder and subject to changes in tidal cross-currents, which mainly cause deviations of course from the channel centre line. Since the length to beam ratio of large vessels lies generally between 5.5 and 6.5, the channel width to beam ratio given above can be interpreted in terms of length.

18.5 Other operational aspects. In addition to the hydro-dynamic effects discussed in 18.1 to 18.4, other related operational aspects should be considered at an early stage.

Winds can impose operating limits on a port and its attendant waterways due to the increased difficulty of handling certain types of vessel in strong winds and to the impossibility of tugs and mooring boats working satisfactorily when the significant wave height exceeds a certain value.

The geometry of the dredged channel can have an effect on the speed at which a ship may be able to pass along it. This transit speed clearly is of importance to port operations as it affects the capacity of the waterways of the port as well as the day to day programming of ship movements.

Of similar significance is the decision to be taken regarding the advisability of two-way traffic and whether one-way traffic is appropriate for ships above a certain limiting size. When two ships pass they interact with each other to a greater or lesser degree, the severity of the effect being increased with reduced underkeel clearance, increased speed and reduced separation between the vessels. In general the overtaking encounter is best avoided, unless the vessels are extremely manoeuvrable, because the vessels remain in close proximity for an appreciable length of time which allows the large interaction forces to become well established. This restriction clearly has an effect on operations within the waterway, traffic in a given direction proceeding, of necessity, in a convoy system at the speed of the slowest vessel. In such a case the longitudinal separation between ships is of importance, affecting both safety of operation and capacity of the waterway. For one-way operations the longitudinal separation is largely determined by the distance required to stop a vessel in a controlled emergency stop. In two-way operation this separation should be further increased in the interests of safety to allow an oncoming vessel sufficient time after passing one convoy vessel to regain course before encountering the next.

19 Ship handling

19.1 Manoeuvring inside harbours. Ship handling should be fully considered in relation to the layout and dimensions of channels, turning circles and positioning of structures, taking account of the range of tides, currents and waves and the assistance available in the form of pilotage, tugs and navigational aids.

At the immediate approach to the harbour entrance, sea conditions may sometimes be rougher than elsewhere, due to the steepening of waves on an ebbing tide, offshore wind or reflection of waves from the harbour walls or breakwaters when these are steep sided. Accordingly, there will be a minimum velocity required to maintain safe steerage when entering the harbour but thereafter the vessel has to be brought to a standstill and the stopping length is frequently limited. It is customary for large vessels to carry out crash-stop trials at sea. However, such tests are not directly applicable inside harbours where the conditions are characterized by confined water, for both depth and width, low speeds, tug assistance and manoeuvres with rudder and propeller to hold course. While stopping lengths can be estimated they are probably best determined by model experiments (see 18.2) if the area available is critical.

Inside the harbour, vessels frequently have to be turned and generous water areas should be provided for this and other manoeuvres. As a general guide, a turning circle with a diameter of four times the ship's length should be allowed where no tug assistance is available. The diameter may be halved where tugs are used regularly and may be further reduced if the critical vessels are equipped with bow thrusters. These average figures should be adjusted, if necessary, for local wind, wave and current conditions and for particular vessel or operator requirements, especially where the underkeel clearance is small.

19.2 Berthing. Full discussion of operational practices at a planned berth should be held with pilots, ships' masters and port operators whenever possible, with a view to determining the optimum layout for safe usage and the design parameters necessary for assessing berthing impact loads (see clause 41).

Large vessels, such as bulk carriers and the larger container ships, are usually brought to rest a short distance off the jetty or quay and then manoeuvred on to the quay with the aid of tugs. Jetty-based electronic instrument systems can be provided to indicate speed and distance from the jetty during this manoeuvre, thus assisting the pilot to keep within the maximum allowable speed and the angle of approach for which the fendering system and jetty layout has been designed.

The employment of tugs may be compulsory in a port although the choice of how many will be the decision of the ship's master who will be guided by the pilot regarding local conditions and requirements. The number of tugs required for berthing depends upon the size of the ship, its power to weight ratio and the speed and direction of the current and winds relevant to the berth. Where no tugs, or insufficient tugs in terms of power or number, are used, the likelihood of excessive impacts is much greater. Where a ship is equipped with a bow thruster, this may reduce the number of tugs required to handle the vessel but can cause erosion problems at some berths.

For large bulk carriers, adequate pilotage and tug power should be provided as a matter of course. Berths for such vessels over 200 000 dwt should have velocity of approach monitoring equipment and should have a display to inform those on board the ship of the transverse approach velocity.

Ships which make a bow or stern approach to a berth under their own power, such as ferries and ro-ro vessels need special measures to ensure quick and safe ship operations, and full discussions with the relevant operators and authorities are essential.